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An investigation of the effects of weight geometry and time in repeated tension impact testing

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California Institute of Technology

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GALCIT REPORT NO.______

GUGGENHEIM AERONAUTICS LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

P21

THESIS

AN INVESTIGATION OF THE EFFECTS OF WEIGHT GEOMETRY AND TIME IN REPEATED TENSION IMPACT TESTING

by

Commander S. R. Ours, Jr., U.S.N.

and

Commander W. G. Jackson, Jr., U.S.N.

Thesis
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AL-5 10M 9-41

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In Partial Fulfillment of
The Requirements for the Professional
Degree of Aeronautical Engineer
1944

ACKNOWLEDGEMENT

The authors wish to express their gratitude for the cooperation and suggestions of the following members of the staffs of the Guggenheim Aeronautical Laboratory and the Impact Laboratory, California Institute of Technology: Dr. Th. von Kármán, Dr. C. B. Millikan, Dr. D. S. Clark and Dr. P. E. Duwez.

They are especially indebted to Dr. E. E. Sechler under whose direct personal supervision the investigation was conducted.

AN INVESTIGATION OF THE EFFECTS
OF
WEIGHT GEOMETRY AND TIME
IN
REPEATED TENSION IMPACT TESTING

SUMMARY

The investigation covered in this report was conducted with the Falling-Carriage Repeated Tension Impact Machine at the Guggenheim Aeronautical Laboratory, California Institute of Technology, Pasadena, California.

Twenty-eight aluminum alloy test specimens were subjected to a total of 7,834 impacts in the GALCIT Falling-Carriage Repeated Tension Impact Machine. Since the average number of impacts per specimen was about 280 it is believed that this investigation covered a regime different from other investigations made with this equipment.

The effect of elapsed time between series of impacts was not established. The results obtained were contradictory, and it is believed that this was due to the energy per impact being variable and unknown.

It is established that the geometry of the weight used in this type of test has some influence upon the elongation produced.

It is shown that 17S-T Duralumin is relatively sensitive to stress concentrations caused by change in cross-section and strain wave reflection, and relatively insensitive to stress concentrations due to small scribe marks.

Evidence is presented to indicate that the elongation at fracture of a specimen subjected to repeated tension impact is inversely proportional to the number of impacts required to produce fracture.

Suggestions are offered for improving the test equipment so as to obtain more nearly consistent results.

INTRODUCTION

Previous investigations made with the Falling-Carriage Tension Impact Machine have shown the possibility that the geometry of the weight attached to the specimen might have some effect upon the elongation produced and the energy absorbed by the specimen. This thought was especially brought about by the fact that the authors of reference 5 had, in one group of specimens, obtained a value of "K" greater than unity, indicating that the energy absorbed by the specimen was greater than the energy available. It was believed that stress waves reflected from the end of the weight might have caused this phenomenon. Therefore, it was decided to test several specimens using weights of the same mass, but differing by a large amount in length.

The results of the above phase of the project were not conclusive and there was considerable evidence to indicate that the interval of time between series of impacts might have had a marked influence on the elongation produced in the specimen. It was, therefore, decided to make a series of tests to determine whether or not time was having the indicated effects. The results of the first tests appeared to show that the time interval between each series of sixty impacts had a very marked effect upon the elongation per impact. In order to make certain of this apparent effect, the tests were repeated on another series of specimens. This second series failed completely to substantiate the results of the first series.

In attempting to explain the above discrepancy it was deducted that the speed of fall of the carriage had not been constant and that it was impossible to determine what the speed had been. This fact makes some of the results doubtful and some of the conclusions only tentative.

The investigation was limited to eight-inch specimens of 2S, 17S-T, and 24S-T aluminum alloys tested in tension impact at velocities of 13.2 feet per second and below.

The investigation was conducted by the authors at the Guggenheim Aeronautical Laboratory, California Institute of Technology, Pasadena, California, during the period from December 1943 to May 1944.

EQUIPMENT

This investigation is one of a series of coordinated projects in the field of repeated tension impact using the GALCIT falling-carriage testing machine. Essentially this machine consists of a falling carriage which moves on vertical guides above a heavy anvil. The upper end of a specimen is screwed into the carriage and to the lower end is screwed a weight of the desired mass. In the anvil, under the center of the carriage, is a hole through which the weight and specimen may pass. The carriage, specimen and weight are raised to the desired height, then released. The carriage falls along the guides until it is stopped abruptly by the anvil. The weight, however, continues on through the hole in the anvil and therefore exerts a dynamic tensile force on the specimen. A photograph of the machine is shown in Fig. 1, and a complete description is given in reference 2 by Beardsley and Coates, who designed the equipment.

An instrument known as a "comparator" was used to place fine scribe marks at intervals of one inch along the length of the specimen and to measure the elongation. The instrument consists of a stationary frame to which the specimen is attached, and a movable head which is driven by a screw of small pitch. Attached to the head are two mounts: one for the razor blade used in making the scribe lines, and one for a microscope used in measuring the elongation. The position of the head is accurately indicated by a micrometer connected to the screw shaft.

The specimens used were machined from standard bar stock of 17ST, 24ST, and 2S aluminum alloys. All specimens were eight inches long, between the shoulders, and were polished to remove machining marks. The two types of specimens used differed only in the fillet radius and the collar at the weight end. The dimensions and details of manufacture of both types are given in Figs. 2 and 3.

PROCEDURE AND RESULTS

Before the tests were started the impact machine was overhauled and carefully inspected. The carriage guides were accurately aligned with shims and lubricated with graphite so that the carriage moved freely and with small play on the guides. The trip latches were adjusted so that each latch tripped at the same height, and the cam was set so as to release the carriage for a fall of thirty-three inches.

The velocity of fall of the carriage was measured as accurately as practicable with a one-thirtieth second spark timer and was found to be, within the accuracy of the measuring equipment, equal to the velocity of free fall, that is, $\sqrt{2gh}$, or 13.2 feet per second. This check on the velocity of fall agreed with the results of previous investigators who had used the falling machine, and it was therefore assumed throughout the remainder of the tests that the velocity of the carriage was the velocity of free fall.

It was decided to attempt to check the results obtained by Lee and Stirling, as given in reference 5. Using the same height of fall (thirty-three inches), the same weight (3.923 lbs.), and the same type of specimen (eight inches, 17S-T), it was believed that approximately the same elongation and number of impacts to break would be obtained. Specimen C-1 to C-5 inclusive were used for this purpose. The results obtained failed to agree with the results as given in reference 5. Actually, specimen C-3 to C-5 inclusive showed no elongation after the first sixty impacts. Since the velocity of the carriage had just previously been checked, and since the stress produced in each impact was quite near the yield point of the material it was believed that the small amount of cold work done on the specimen during the first impacts had raised the yield point so that the following impacts were in the elastic range. To check this possibility static tension tests were made with two test bars made from the same stock used for the specimen. The average ultimate strength of these two bars was 67,250 p.s.i., whereas the maximum strength shown for 17S-T in reference 5 was 63,500 p.s.i. The superior strength of the 17S-T stock used in the present tests apparently explained the failure to reproduce previous results, and it was therefore decided to increase the mass of the weight on succeeding tests. Also a chemical analysis of the stock being used was made which definitely established the material as 17S-T duralumin.

For the remainder of the tests, excepting those made with 2S material, two weights of 5.923 pounds were used. One of these weights was three inches in diameter and three inches long, while the other weight was 1.732 inches in diameter and nine inches long.

To investigate the effect of weight geometry, four specimens were subjected to impacts until fracture occurred using a height of fall of thirty-three inches. The three inch weight was used on specimens C-6 and C-7 and the nine inch weight was used on specimens C-8 and C-9. The elongation was measured after each thirty impacts. A graph of total elongation versus number of impacts for these four specimens is shown in Fig. 4. These curves show somewhat different patterns for the three inch weight than for the nine inch weight in that most of the elongation occurs after a larger number of impacts for the longer weight. The study of the influence of weight geometry was continued in succeeding tests.

Two other features of these curves were noted. First, specimens C-6, C-7, and C-9 fractured in the fillet, with an average elongation at break of 0.341 inches, but specimen C-8, which did not break in the fillet, showed an elongation of 0.781 inch at fracture. A review of previous tests on similar specimens showed that nearly all the fractures had been in the fillet. Therefore, the C-type specimen was altered in that the fillet radius was changed from 1/32 inch to 1/4 inch, and a collar was added to the weight end to facilitate marking and the measuring of the elongation. The twenty-two succeeding specimens were of this altered design, and only one of them failed in the fillet.

The second feature noted is exemplified by specimen C-8. The first ninety impacts on this specimen were performed in one day. During the first sixty of these the elongation per impact, or the slope of the curve, was fairly constant, but during the next thirty impacts the curve levels off and no elongation was produced. This tendency of the elongation per impact to decrease and approach zero after a certain number of impacts is obvious in all these curves. But after five days elapsed time specimen C-8 was subjected to further impacts and the elongation per impact again became nearly constant, with the curve having a somewhat increased slope. A similar effect was noted in several other specimens, and an investigation of the effect of elapsed time between series of impacts seemed warranted and was undertaken.

Using specimens with the 1/4 inch fillet radius and employing weights of both three and nine inch lengths, test specimens D-1 to D-6 were subjected to impacts, with a height of fall of thirty-three inches, according to the following time schedule:

Specimen Number	Weight Length	Time Schedule of Impacts
D-1	9 in.	60 impacts every third day.
D-2	3	60 " " " "
D-3	9	Completed in one day.
D-4	3	" " " "
D-5	9	60 impacts every second day.
D-6	3	60 " " " "

The results of these tests are shown as a plot of elongation versus number of impacts in Fig. 5. This graph indicated that the time interval between each series of sicty impacts apparently had a major effect upon the impact properties of the material. It was therefore proposed to conduct similar tests to reproduce these results, using specimens made from 17S-T, 24S-T, and 2S stock.

Specimens made from 2S stock were designated type G, and numbers G-1 and G-2 were tested to fracture using a weight of 1.945 pounds. Testing of each of these specimens was completed in one day, but they were tested on two different days, six days apart. The data are plotted in Fig. 6 which shows that the results for the two specimens are widely different, although the conditions of the test were supposedly the same. Specimens made from 24S-T stock were designated type F, and numbers F-1, F-2, and F-3 were then tested to fracture, each being completed in one day. A graph of elongation versus number of impacts for these specimens is shown in Fig. 7, and again the curves are inconsistent for no apparent reason. It appeared that some unaccounted for parameter was of major importance.

The tests were thereafter limited to 17S-T specimens using only the nine inch weight of 5.923 pounds. Specimen D-1 was subjected to continual impacts in one day and fracture occurred after ninety-two impacts. Sepcimens D-3 and D-4, tested similarly, required 675 and 538 impacts respectively. The slope of the curve for specimen D-1 was nearly constant, but the curves for the other two specimens were horizontal over a large number of impacts.

In attempting to explain this very erratic behavior a study was made of all tests made to date. The only logical conclusion which could be reached was that the velocity of the carriage had not been constant. In order to produce the results shown in Fig. 5 it was necessary that the velocity not only had changed, but that it had changed at just the proper time and in the right amount for all six of the D-type specimens. This was necessary in order to produce three sets of two specimens each in which the slope of each pair of specimens was about the same but changed by large amounts from one set to the other. This conclusion, that the velocity had varied in this unfortunate manner, which conclusion is still not definitely proved, is accepted tentatively because of an inability to explain the results obtained in any other manner. An attempt to show how this conclusion was reached is given in Fig. 8.

It was believed that if Fig. 5 could be reproduced it would have to be done with a velocity of impact (holding the weight at 5.923 lbs.) such that a large number of impacts would be required for fracture in one day. The height of fall was therefore progressively reduced on the "E" specimen until a low energy level was reached.

Specimen E-9, with a dropping height of 16.5 inches required 841 impacts for fracture in one day, and the elongation per impact was nearly constant. With this same dropping height specimen E-10 was subjected to sixty impacts every other day, and E-11 was subjected to sixty impacts every third day. The results are shown in Fig. 9. For all three of these specimens the elongation per impact was of the same order and nearly constant, and the average number of impacts to fracture was 719. The fact that time elapsed between series of impacts has any marked effect upon elongation per impact was now apparently disproved, and the conclusion that the speed of the carriage had varied over a wide range was tentatively corroborated.

The data obtained for each specimen tested is given in Table I. The essential data taken were: the weight of the mass causing the impact, the height of fall of this weight, and the elongation produced in the specimen. It is believed that the weight of the mass causing impact was accurate to within 0.05 pounds, that the height of fall was accurate to within 0.15 inch, and that the elongations were measured to within 0.001 inch.

A suggested procedure for taking repeated tension impact data with the equipment available at the California Institute of Technology is included herewith as Appendix B.

DISCUSSION OF RESULTS

Fig. 5 shows an apparent effect of elapsed time upon the impact properties of 17S-T duralumin, while Fig. 9 shows that there is no marked effect. A deduction was made that the effect shown in the former figure was due to varying velocities of impact. Nevertheless, it should be emphasized that it is not known definitely that the velocity did change during testing of the D-type specimen, nor that it was nearly constant during the testing of specimen D-9 to D-11. Therefore, it should not be definitely concluded that time has no effect until more accurate data is available. It is concluded, however, that no more investigations should be attempted with the Falling-Carriage Repeated Impact Machine until an accurate method of measuring the velocity of impact is made an integral part of the testing apparatus so that there will be no doubt about the impact velocity. It is also necessary that, for a set height of fall, the velocity of impact be constant as well as accurately measured. Suggestions for alteration of the machine and for design of velocity measuring equipment to obtain these two ends are given in Appendix A.

Referring to columns 8 and 13 of Table I, if a representative group of C-type specimens is selected and another representative group of the D-type specimen is selected, each group having about the same average number of impacts to produce failure, it is seen that the total elongation at fracture for the "C" group is about 4.2 percent, while the total elongation at fracture for the "D" group is about 14.4 percent.

Actually, the average elongation of all specimens having a 1/32 inch fillet radius was 4.35 percent whereas the average elongation of all specimens having a 1/4 inch fillet radius was 11.70 percent. Fracture of all except one specimen with the 1/32 inch fillet radius occurred in the fillet, while for the specimen with the 1/4 inch fillet radius the breaks were well scattered throughout the specimen length and only one of them occurred in the fillet. This fact is shown in photographs presented as Figs. 10 to 14.

Scribe marks were made with a razor blade at intervals of one inch along the specimen for measuring the distribution of elongation. These marks formed notches of very small radius which were apparently ideal stress concentration points. Throughout the tests many of these marks opened up and formed deep cracks, but in no case did the specimen fracture in one of the marks. It is therefore shown that 17S-T is more susceptible to stress concentrations caused by change of cross-section and strain wave reflection than those caused by small scribe marks.

If a specimen is fractured in a dynamic tension test, that is, by one tension impact, with an impact velocity of approximately 13 feet per second, a certain percent elongation is produced, which for 17S-T is about twelve percent. If a similar specimen is fractured in an endurance limit test, the specimen theoretically has no elongation, since the break occurs after a very large number of stress cycles, of which the maximum stress is below the proportional limit of the material. Now, if other specimens are tested in tension impact so that the number of impacts required for fracture is very large, then it would be expected that the elongation at fracture would decrease in proportion. This is shown to be true for specimens of types E, F, and G in Fig. 15. The points forming these curves have considerable scatter, and the points for the D-type specimen cannot be correlated, but it is believed that if the velocity of the carriage had been both constant and accurately known that the curves would have been well defined and probably of the same slope. It is therefore concluded that the larger the number of impacts required to cause fracture, the less will be the total elongation at break.

A close inspection of columns 7 and 13 of Table I discloses that the average of the total elongations obtained with the nine inch weight was greater than the average of the total elongations produced by the three inch weight. With the data at hand no similar generalization can be made concerning the number of impacts required to cause fracture. It is therefore concluded that the geometry of the weight used has some effect upon the elongation produced in this type of test. No general conclusions regarding the influence of weight geometry can be made, however, since the stress distribution along the specimen at any given time depends upon the direct tension stress and the stresses caused by the plastic and elastic waves. The stresses caused by the plastic and elastic waves depend upon the length of the specimen, the length of the weight, the speed of sound in the specimen, and the speed of sound in the weight. Only one of these parameters, namely, the length of the weight was varied in this investigation. It must also be considered that if a plastic or elastic wave is reflected from the weight and if the stress distribution along the specimen at any given time depends upon the stresses caused by the plastic and elastic waves, which in turn depend upon the length of the weight, then the wave will be again reflected from that part of the machine which is directly attached to the upper end of the specimen, and the stress distribution along the specimen at any given time will also depend upon the geometry of the testing machine. It can, therefore, be concluded only that weight geometry has some influence upon elongation and that an exact correlation of data between any two tests requires that the geometry of both the weight and the testing machine be similar.

In all cases much more than the average elongation per impact was produced on the first impact on each specimen. This fact can be seen by a comparison of the data tabulated in Table I, columns 11 and 13. The elongation per impact then decreased and tended to reach a somewhat constant value near sixty impacts. This phenomenon is illustrated graphically in Fig. 9 by the curves of specimens E-9 to E-11. Due to apparent variations in impact velocity the point at which the elongation per impact became practically constant, was not always the same. It is, however, expected that in any repeated tension impact test the elongation on the first impact will be larger than the average elongation per impact. The explanation for this phenomenon is based upon the assumption that the loading and unloading of the specimen on successive impacts is along lines parallel to the initial slope of the stress-strain curve. This results in an increase in the yield point of the material with the increase in the permanent set of the material. As a result of this increase in the yield point the specimen absorbs elastically a greater percent of the total energy available. Therefore there is less energy available for plastic deformation and less elongation per impact. As soon as the elongation of the specimen is such that, when loading along a line parallel to the initial slope of the stress-strain curve, a point on the stress-strain curve is reached which is close to the ultimate stress the increase per impact in the yield point becomes very small and the elongation per impact tends to become constant. It is to be noted that this phenomenon is most apparent when the number of impacts required to cause failure is large. This is true because the percentage change in the plastic energy per impact is large.

The fact that most of the tests in the early part of the investigation were not completed in one day, nor according to any organized time schedule, was due to frequent failure of the testing machine. Most of the interruptions were caused by fatigue failure of bolts holding the carriage rebound latches. This difficulty was effectively eliminated, the method used being discussed in Appendix A.

Throughout all the tests made with the falling carriage machine, both in this investigation and those discussed in the references, bending of the specimen has occurred. Stirling and Lee attempted to eliminate this fault with the equipment by installing a ball and socket joint between the carriage and the specimen, so that the specimen and weight would hang free without any lateral restraint. Bending persisted throughout the present investigation, and it is the opinion of the authors that this bending is caused by compression buckling of the specimen when the weight rebounds.

An inspection of column 10 in conjunction with the remainder of Table I shows that the buckling has no consistent effect. That is, a small amount or a large amount of buckling cannot be correlated with small or large total elongations or impacts required for fracture. It is therefore stated that the effects of bending of the specimen upon tension impact testing, if there are any effects, are unknown. At any rate, the bending forms another unknown and should be eliminated in order to reduce as far as possible the number of parameters. A suggestion for improving this characteristic of the equipment is made in Appendix A.

Figs. 16 to 25 inclusive are presented to show the distribution of elongation of typical specimen tested. This distribution is similar to that presented in reference 5 in that the greatest unit elongation occurs near the ends of the specimen. A close examination of these curves of distribution of elongation, of the specimen subjected to impact with the nine inch weight and those subjected to impact with the three inch weight, shows that the greater total elongation at break shown by all specimens subjected to impact with the nine inch weight is a result of the greater unit elongation in the central portion of the specimen. It is believed that this is a result of the difference in the time of the reflection of the strain waves with the three inch and the nine inch weights.

The static stress-strain characteristics of the materials used during the conduct of this investigation are shown in Fig. 25.

An energy analysis of the data taken during this investigation is impossible because the energy available to the specimen is not known to a reasonable accuracy and if it were known such an analysis would still be impossible because the ratio of the plastic energy per impact to the elastic energy per impact is so small that the errors involved in determining the elastic energy per impact are much larger than the quantity to be measured.

CONCLUSIONS

1. It is necessary that an accurate and rapid method of determining the velocity of impact be made an integral part of the repeated tension impact testing equipment.

2. The Falling-Carriage Tension Impact Machine should be modified in whatever manner is necessary to make the velocity of impact constant on successive impacts from a constant height.

3. The geometry of the weight used in this type of test has some effect upon the elongation produced in the specimen. Other conditions being the same, a weight nine inches long produces more elongation than the same weight three inches long.

4. 17S-T duralumin is much more susceptible to stress concentrations caused by changes in cross-section than to those caused by small scribe marks.

5. In tests of the type conducted, the elongation of the specimen at fracture is inversely proportional to the number of impacts required to produce fracture.

6. When the number of impacts is small the fracture of the specimen is accompanied by considerable necking and is of the cup and cone type, whereas, when the number of impacts is large, the fracture is of the fatigue type without any necking of the specimen.

7. When the number of impacts to cause fracture is large the elongation per impact is much larger during the first few impacts than the average elongation caused by all the impacts.

8. The yield point of the material is increased by cold working during tension impact testing and this increase in the yield point results in an increase in the number of impacts to cause failure.

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APPENDIX A

SUGGESTED IMPROVEMENTS IN THE DESIGN OF THE FALLING-CARRIAGE REPEATED TENSION IMPACT MACHINE

The following suggestions are offered as desirable improvements in the design of the Falling-Carriage Repeated Tension Impact Machine:

1. Install four rollers on all triggers.

2. Increase the length of the triggers 3/8" in order that the carriage may be picked up over the center of gravity of the carriage.

3. If item 2 is carried out the slot in the carriage must be milled to accomodate the increase in the trigger length.

4. Increase the size of the brass slipper studs to the next standard size and secure the studs with an efficient lock washer. (The size of the studs at present installed is 3/16".)

5. Remove the stud in the center of the brass slipper. (This stud cannot be seen with the carriage installed.)

6. In place of the stud referred to in item 5, install a bolt through the carriage and the back of the slipper.

7. Increase the depth of the back of the slipper to accommodate a bolt the same size as the slipper studs. If the increase in depth is considered necessary to accommodate the bolt, new slippers must be manufactured.

8. If item 7 is carried out the carriage must be milled to accommodate the new slippers.

9. Bevel the upper and lower edges of the slippers.

10. Install the electric motor on a permanent mounting bracket.

The failure of the bolts holding the carriage rebound latches was eliminated by installing 5/8" pins secured with set screws, in place of the 1/2" bolts.

It is considered mandatory that the installation of the velocity measuring equipment be completed before any additional investigation is made with the subject machine. A suggested system is shown in Fig. 27.

It is recommended that the first attempt to eliminate the buckling problem be made by a decrease in the length of the specimen. This will result in a decrease in the slenderness ratio and a decrease in the total energy available for the production of a compressive force. Both of these effects will tend to eliminate the buckling. If it is considered that the compressive force must be eliminated entirely it is recommended, as a last resort, that a buffer mechanism similar to the recoil and counter-recoil mechanism on a gun be installed between the specimen and the carriage. This is recommended as a last resort because any installation on the carriage is another source of trouble.

APPENDIX B

SUGGESTIONS FOR TAKING REPEATED TENSION IMPACT DATA

The following suggestions are offered to future investigators in order that the time wasted and the mistakes made by the present authors may be eliminated in succeeding investigations:

1. Maintain a watch on the testing machine at all times when it is running. It may go through 98 cycles smoothly and jam on the 99th.

2. Make sure the counter reads zero before beginning a series of impacts.

3. Screw the upper end of the specimen into the carriage, and then screw the weight on the lower end of the specimen.

4. When both ends of the specimen are screwed home, back off a quarter of a turn on both ends. This greatly lessens the difficulty of removing the short end of a fractured specimen when the break occurs very near one end.

5. Keep the project notebook handy at all times and enter in it every bit of available data even though it appears irrelevant. It is suggested that the back of the book be used for recording data taken, instead of using data sheets.

6. If a shipment of material is received which is to be used in manufacturing specimens obtain and record in the notebook all available information concerning the stock and place identifying tags on the stock itself.

7. Check the diameter of all specimens with micrometer calipers.

8. To measure the height of fall of the carriage place a small U-shape metal clip around the guide rails above the carriage. The carriage will slide this clip along the guides to its highest position and then drop away from the clip which then shows the highest point of the top of the carriage.

9. Check the velocity of impact frequently to see that it remains constant.

10. In using the comparator, do not let the hand or any other weight touch the frame to which the specimen is attached or the microscope.

11. In marking the specimen, make the scribe lines very light. If this is properly done there will be no failures in the scribe marks.

12. After marking the specimens check the positions of the scribe marks with the microscope, and record the actual positions of the marks rather than the intended positions.

13. In reading elongations always bring the microscope cross-hairs up to each scribe line from one direction.

14. In focusing the microscope always make the last movement in the downward direction.

TABLE I

REPEATED TENSION IMPACT DATA

1	2	3	4	5	6	7	8	9		10	11		12		13		14
SPECIMEN NUMBER	MAT'L.	SPECIMEN LENGTH INCHES	FILLET RADIUS INCHES	HEIGHT OF FALL INCHES	WEIGHT LBS.	LENGTH OF WT. INCHES	IMPACTS TO BREAK	LOCATION OF BREAK		BUCKLING	TOTAL ELONGATION FIRST IMPACT		TOTAL ELONGATION SIXTY IMPACTS		TOTAL ELONGATION BREAK		SPECIMEN NUMBER
								INCHES	PERCENT OF LENGTH		INCHES	PERCENT	INCHES	PERCENT	INCHES	PERCENT	
C-1	17ST	8	1/32	33.0	3.930	2	166	8.17	98.8	NO	0.017	0.21	0.105	1.31	0.182	2.28	C-1
C-2	17ST	8	1/32	33.0	3.930	10.65	91	8.05	99.0	NO	0.013	0.16	0.060	0.75	0.097	1.21	C-2
C-6	17ST	8	1/32	33.0	5.923	3	266	0.03	0.4	MODERATE	0.009	0.11	0.235	2.94	0.300	3.75	C-6
C-7	17ST	8	1/32	33.0	5.923	3	331	8.40	99.2	" "	0.008	0.10	0.133	1.66	0.372	4.65	C-7
C-8	17ST	8	1/32	33.0	5.923	9	256	8.60	96.0	" "	0.014	0.18	0.088	1.10	0.781	9.76	C-8
C-9	17ST	8	1/32	33.0	5.923	9	207	8.34	98.8	" "	0.015	0.19	0.125	1.56	0.349	4.36	C-9
D-1	17ST	8	1/4	33.0	5.923	9	117	0.73	7.9	NO	0.018	0.22	0.267	3.34	1.181	14.80	D-1
D-2	17ST	8	1/4	33.0	5.923	3	134	0.60	6.6	SLIGHT	0.015	0.19	0.247	3.06	1.080	13.50	D-2
D-3	17ST	8	1/4	33.0	5.923	9	675	1.02	11.2	" "	0.014	0.18	0.098	1.23	1.068	13.35	D-3
D-4	17ST	8	1/4	33.0	5.923	3	538	8.08	97.1	" "	0.024	0.30	0.208	2.60	0.306	3.82	D-4
D-5	17ST	8	1/4	33.0	5.923	9	584	8.66	95.5	NO	0.017	0.21	0.227	2.84	1.050	13.12	D-5
D-6	17ST	8	1/4	33.0	5.923	3	185	8.29	94.5	NO	0.022	0.28	0.291	3.64	0.770	9.62	D-6
E-1	17ST	8	1/4	33.0	5.923	9	92	0.58	6.4	SEVERE			0.637	7.96	1.098	13.70	E-1
E-2	17ST	8	1/4	31.4	5.923	9	77	8.24	89.0	NO			0.969	12.15	1.249	15.60	E-2
E-3	17ST	8	1/4	33.0	5.923	9	95	1.50	16.0	NO			0.871	10.90	1.357	16.95	E-3
E-4	17ST	8	1/4	34.5	5.923	9	47	3.16	34.2	NO			——	——	1.220	15.25	E-4
E-5	17ST	8	1/4	31.5	5.923	9	86	7.82	85.0	NO			0.895	11.20	1.204	15.05	E-5
E-6	17ST	8	1/4	26.0	5.923	9	98	0.50	5.6	MODERATE			0.495	6.20	0.988	12.35	E-6
E-7	17ST	8	1/4	21.6	5.923	9	141	0.46	5.0	NO			0.600	7.50	1.160	14.50	E-7
E-8	17ST	8	1/4	19.0	5.923	9	424	8.42	93.7	SLIGHT			0.373	4.69	0.988	12.35	E-8
E-9	17ST	8	1/4	16.5	5.923	9	841	2.13	25.1	NO			0.150	1.88	0.490	6.12	E-9
E-10	17ST	8	1/4	16.5	5.923	9	618	4.30	50.0	MODERATE			0.199	2.49	0.579	7.24	E-10
E-11	17ST	8	1/4	16.5	5.923	9	698	8.12	94.6	SLIGHT			0.179	2.24	0.586	7.33	E-11
F-1	24ST	8	1/4	33.0	5.923	9	456	8.18	96.5	SEVERE			0.107	1.34	0.465	5.82	F-1
F-2	24ST	8	1/4	33.0	5.923	9	173	4.50	50.3	" "			0.419	5.24	0.948	11.85	F-2
F-3	24ST	8	1/4	33.0	5.923	9	135	0.50	55.5	MODERATE			0.492	6.15	1.007	13.40	F-3
G-1	2S	8	1/4	33.0	1.945	2.25	271	0.54	6.2	SLIGHT			0.158	1.93	0.695	8.69	G-1
G-2	2S	8	1/4	33.0	1.945	2.25	53	0.64	7.1	NO			——	——	1.062	13.30	G-2

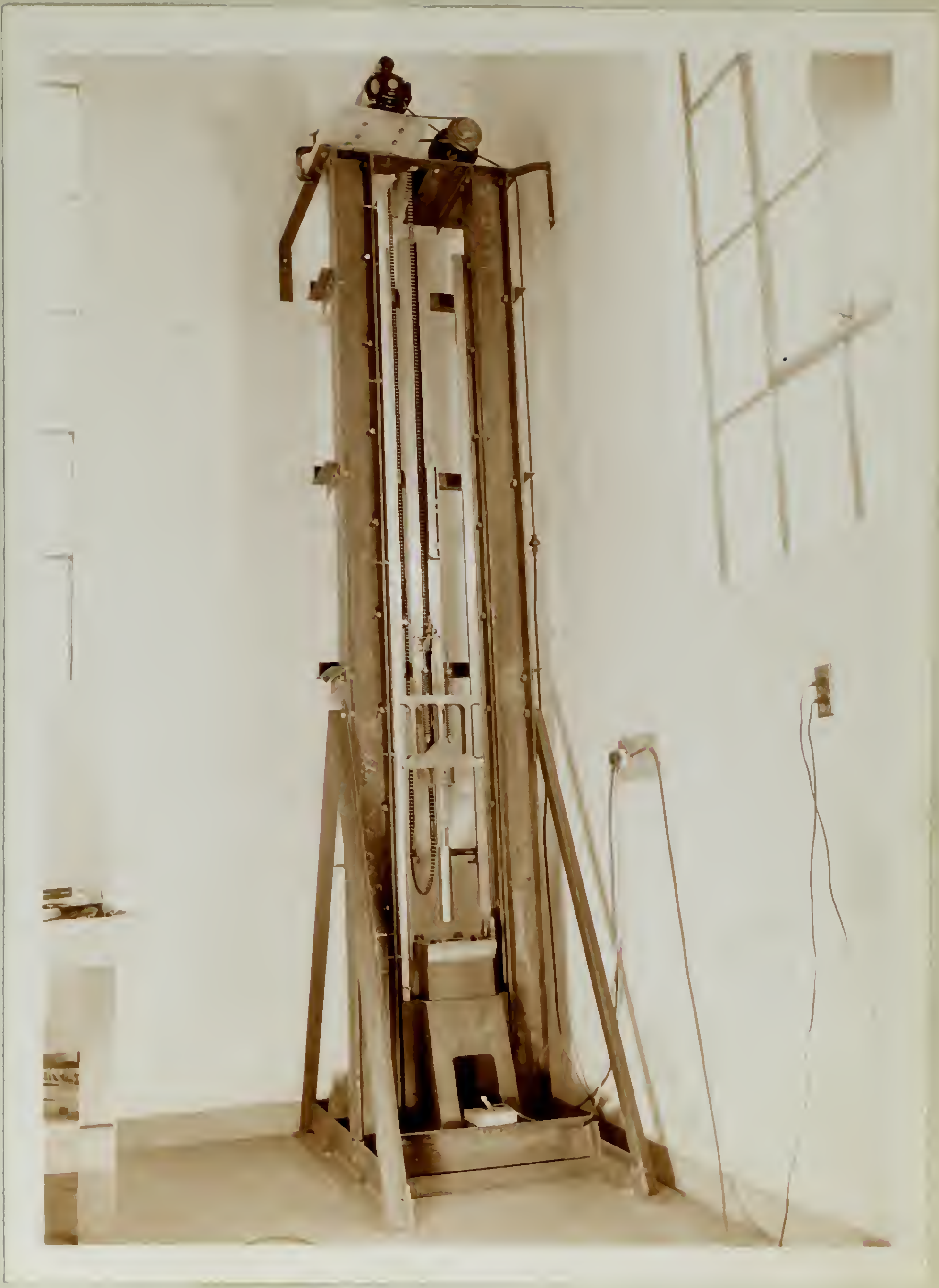


Fig. 1 Falling Carriage Tension Impact Machine

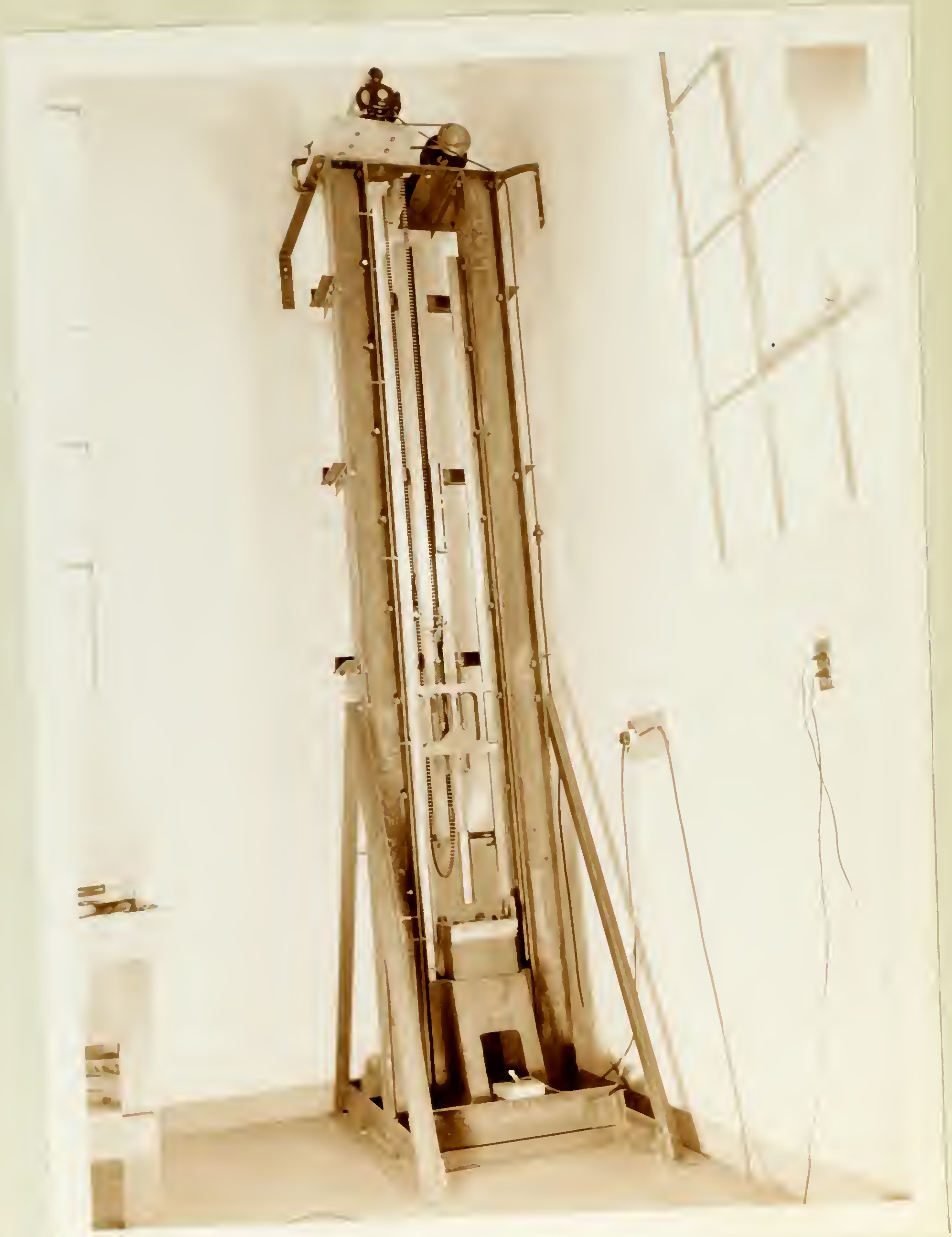


Fig. 1 Falling Carriage Tension Impact Machine

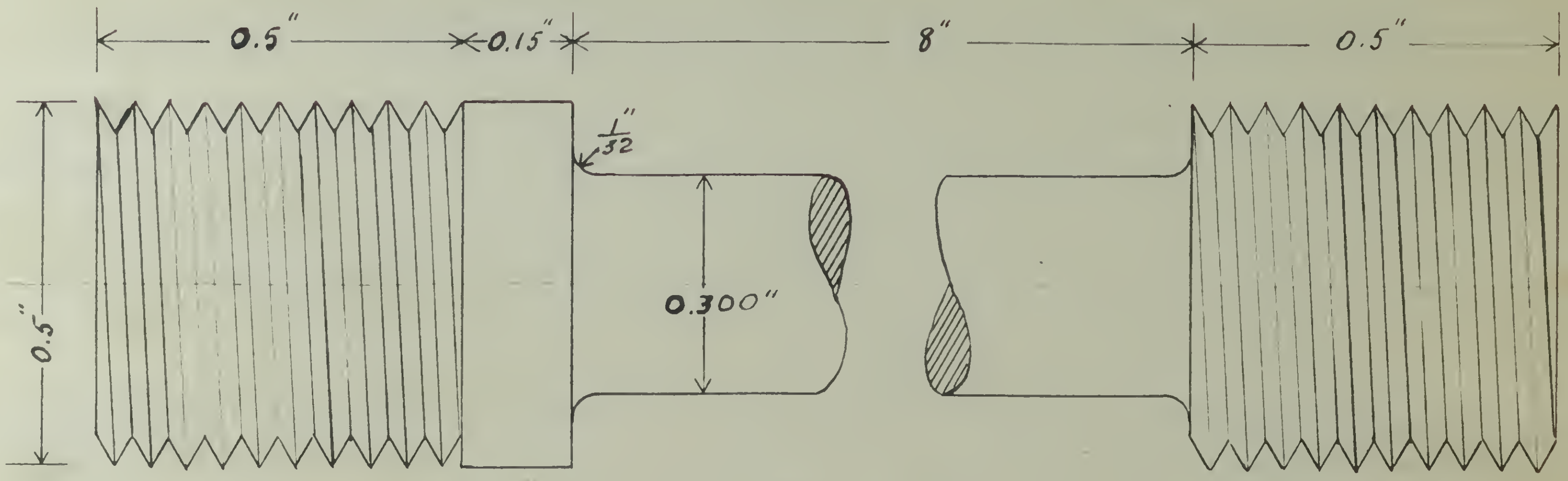


FIG. 2

MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	TOLERANCES ± .010 OR $\frac{1}{64}$ UNLESS OTHERWISE NOTED

GUGGENHEIM AERONAUTICAL LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

TEST SPECIMEN
TYPE C

NAME

DRAWING NO.

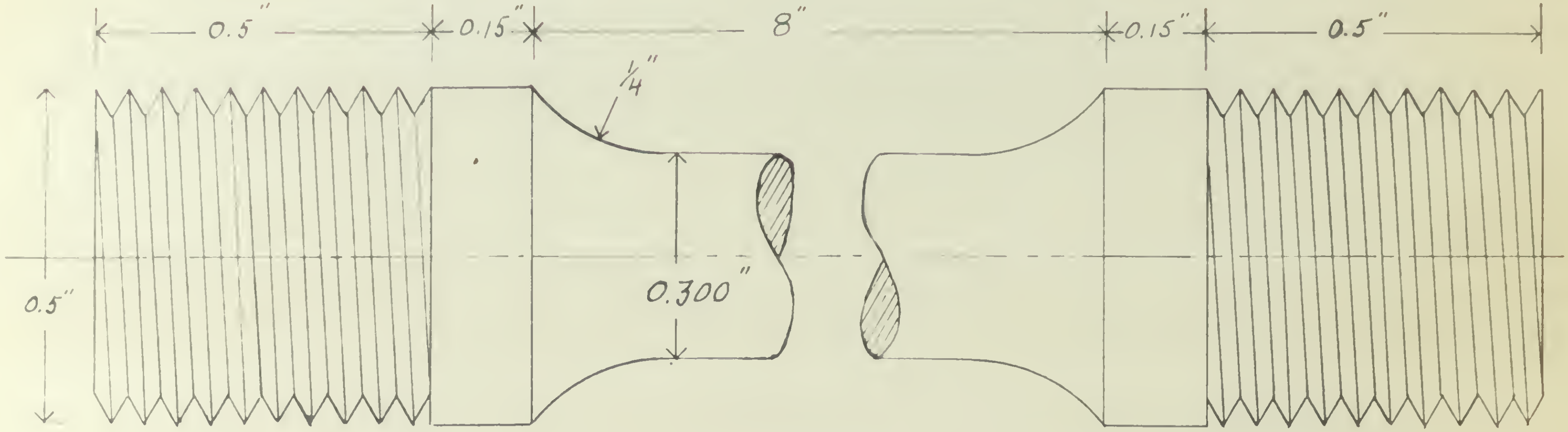
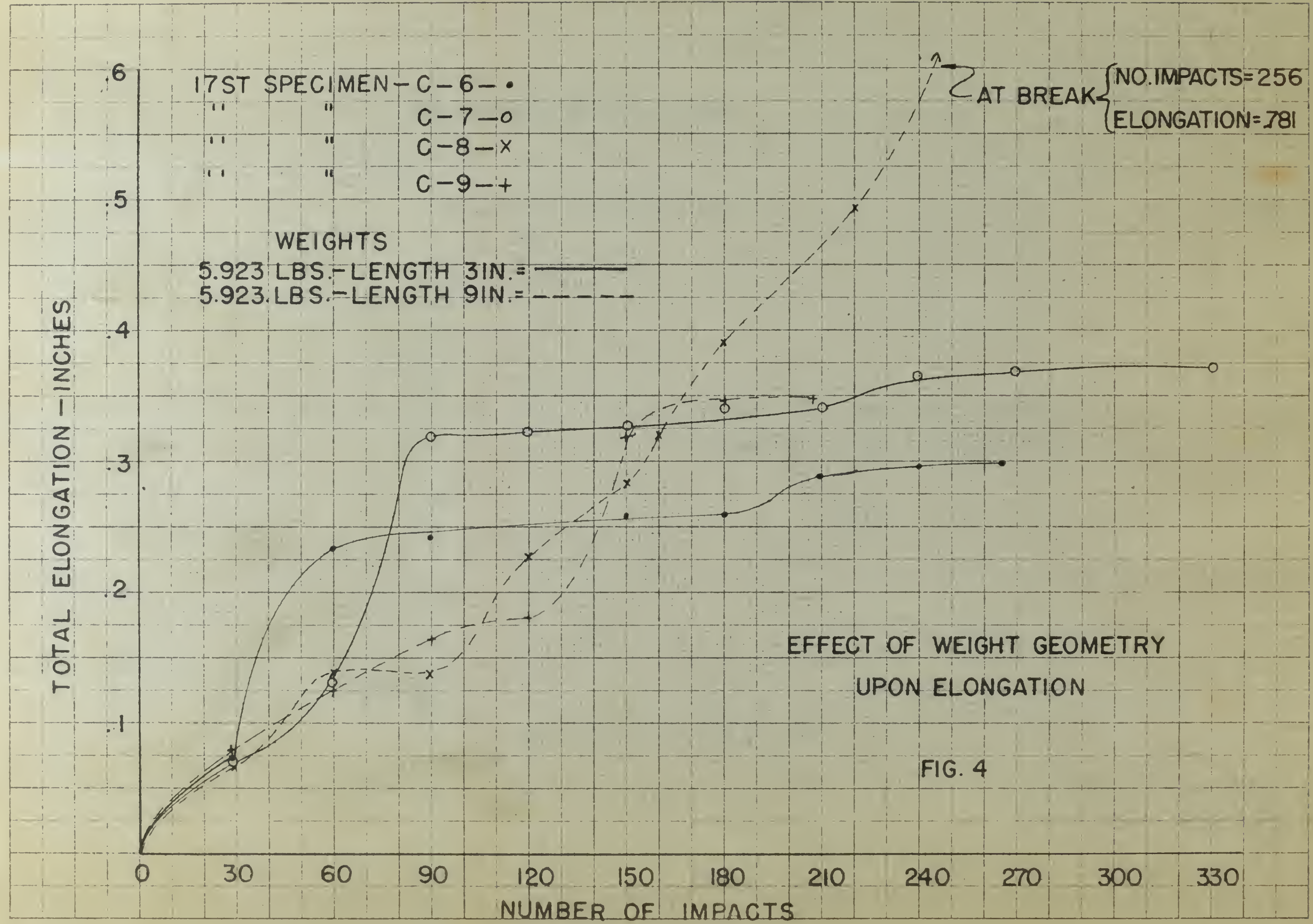


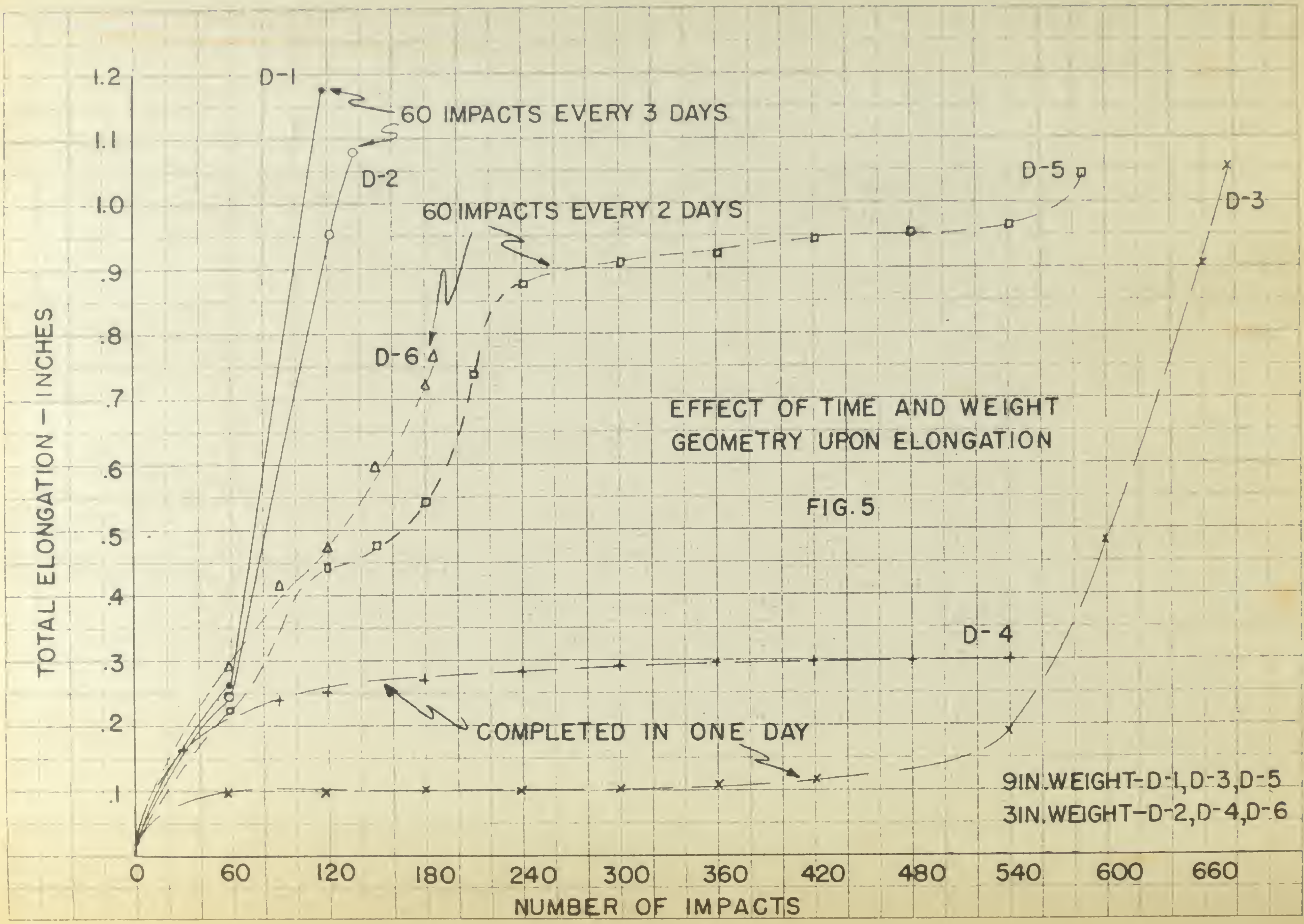
FIG. 3

							TOLERANCES ± .010 OR $\frac{1}{64}$ UNLESS OTHERWISE NOTED
MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			TEST SPECIMEN TYPES D E F G				
			NAME				DRAWING NO.



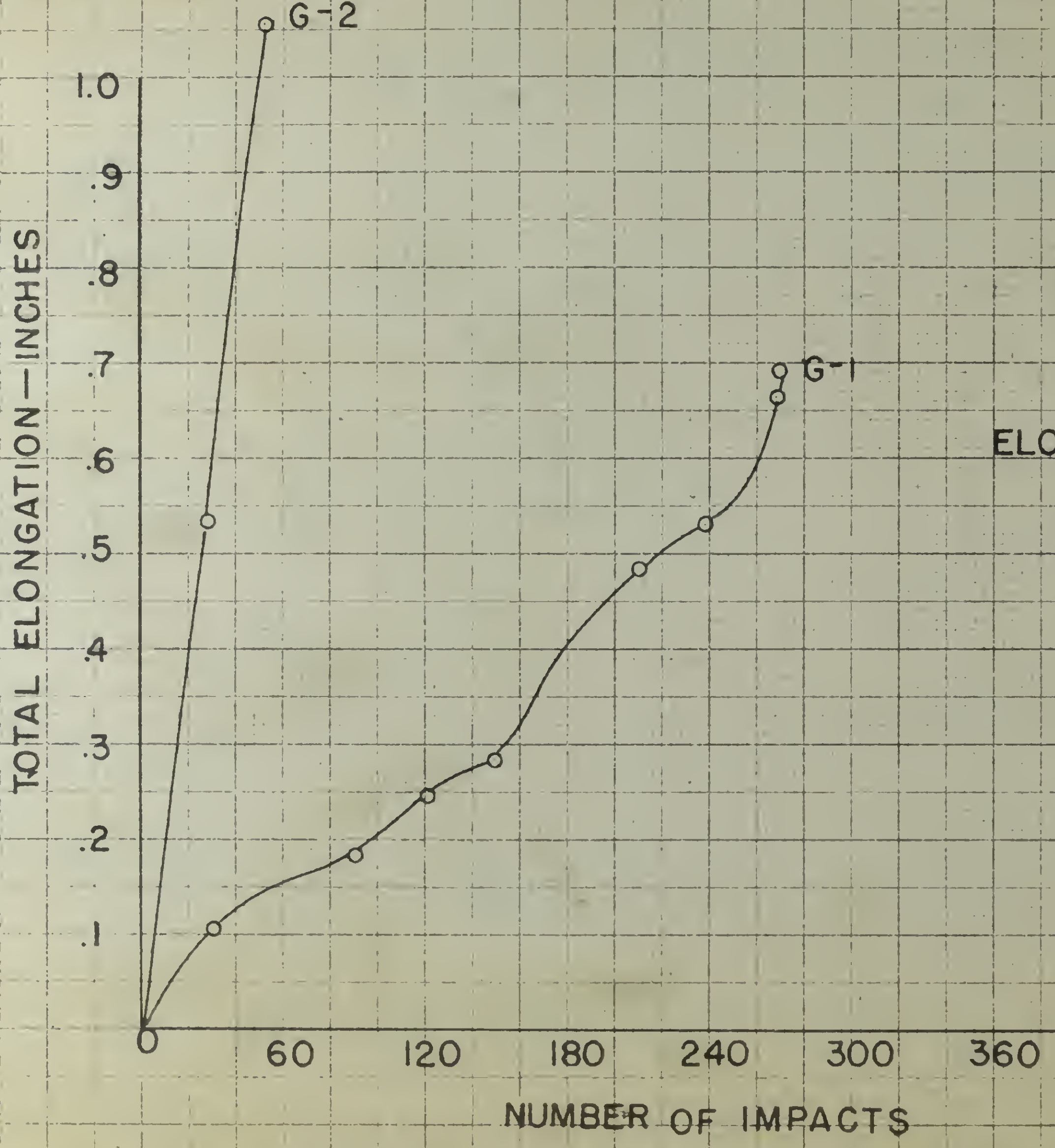
EFFECT OF WEIGHT GEOMETRY
UPON ELONGATION

FIG. 4



EFFECT OF TIME AND WEIGHT GEOMETRY UPON ELONGATION

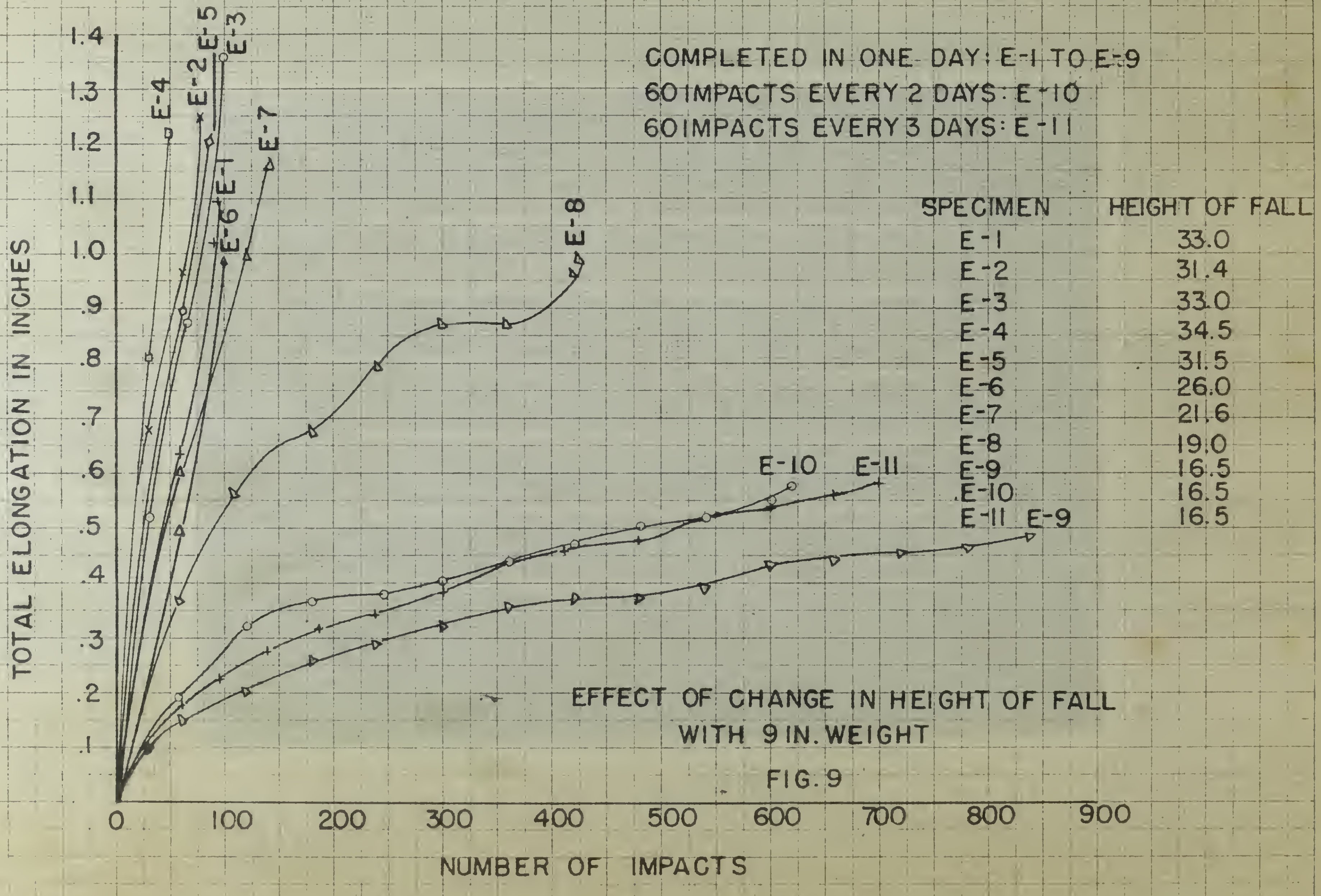
FIG. 5



ELONGATION VS. NUMBER OF IMPACTS
2S SPECIMENS
EACH COMPLETED IN ONE DAY

FIG. 6

WEIGHT: 1.945 LBS.
LENGTH=2.25 IN.



COMPLETED IN ONE DAY: E-1 TO E-9
60 IMPACTS EVERY 2 DAYS: E-10
60 IMPACTS EVERY 3 DAYS: E-11

SPECIMEN	HEIGHT OF FALL
E-1	33.0
E-2	31.4
E-3	33.0
E-4	34.5
E-5	31.5
E-6	26.0
E-7	21.6
E-8	19.0
E-9	16.5
E-10	16.5
E-11	16.5

EFFECT OF CHANGE IN HEIGHT OF FALL
WITH 9 IN. WEIGHT

FIG. 9

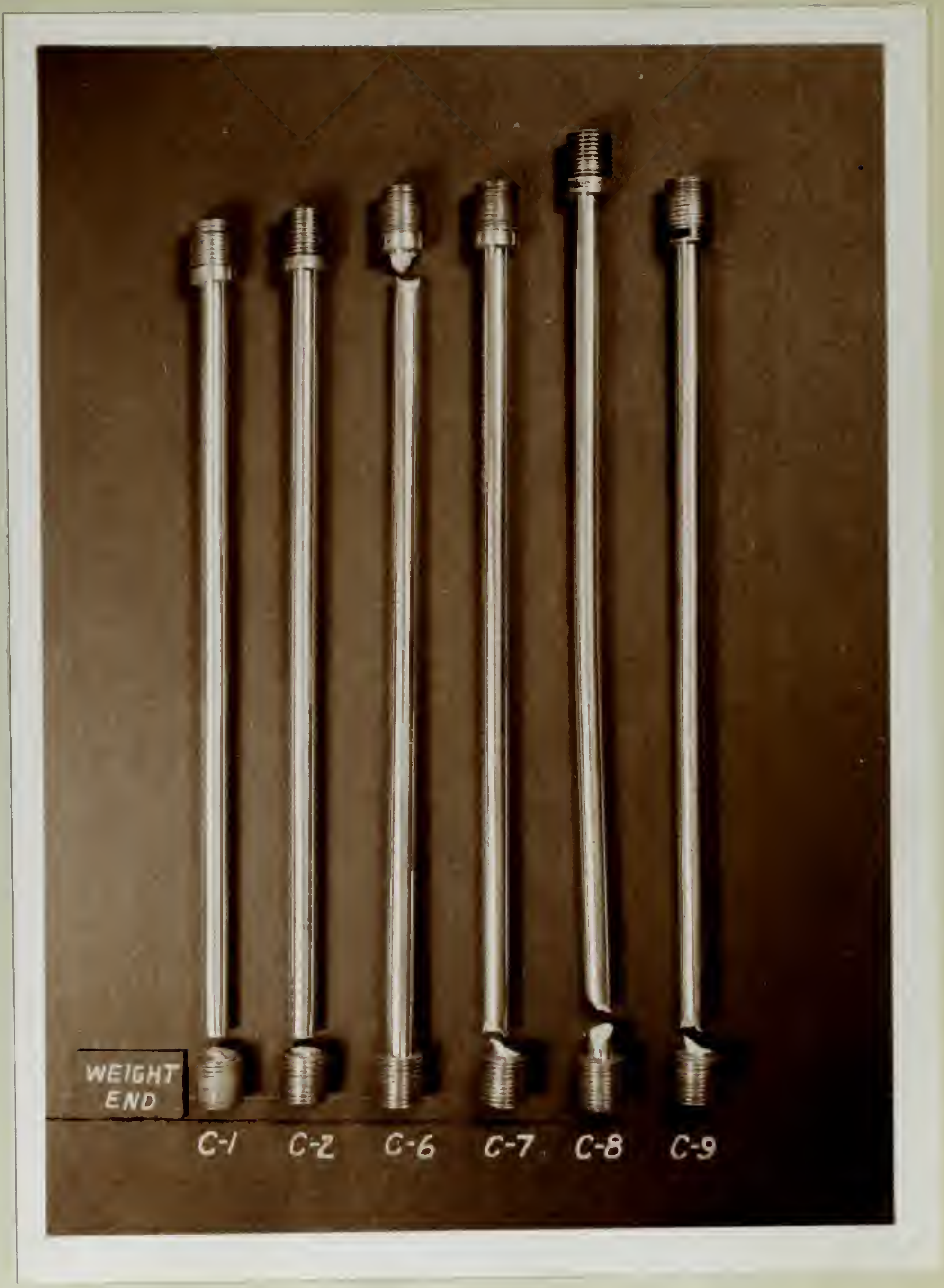


Fig. 10 C Specimens After Fracture

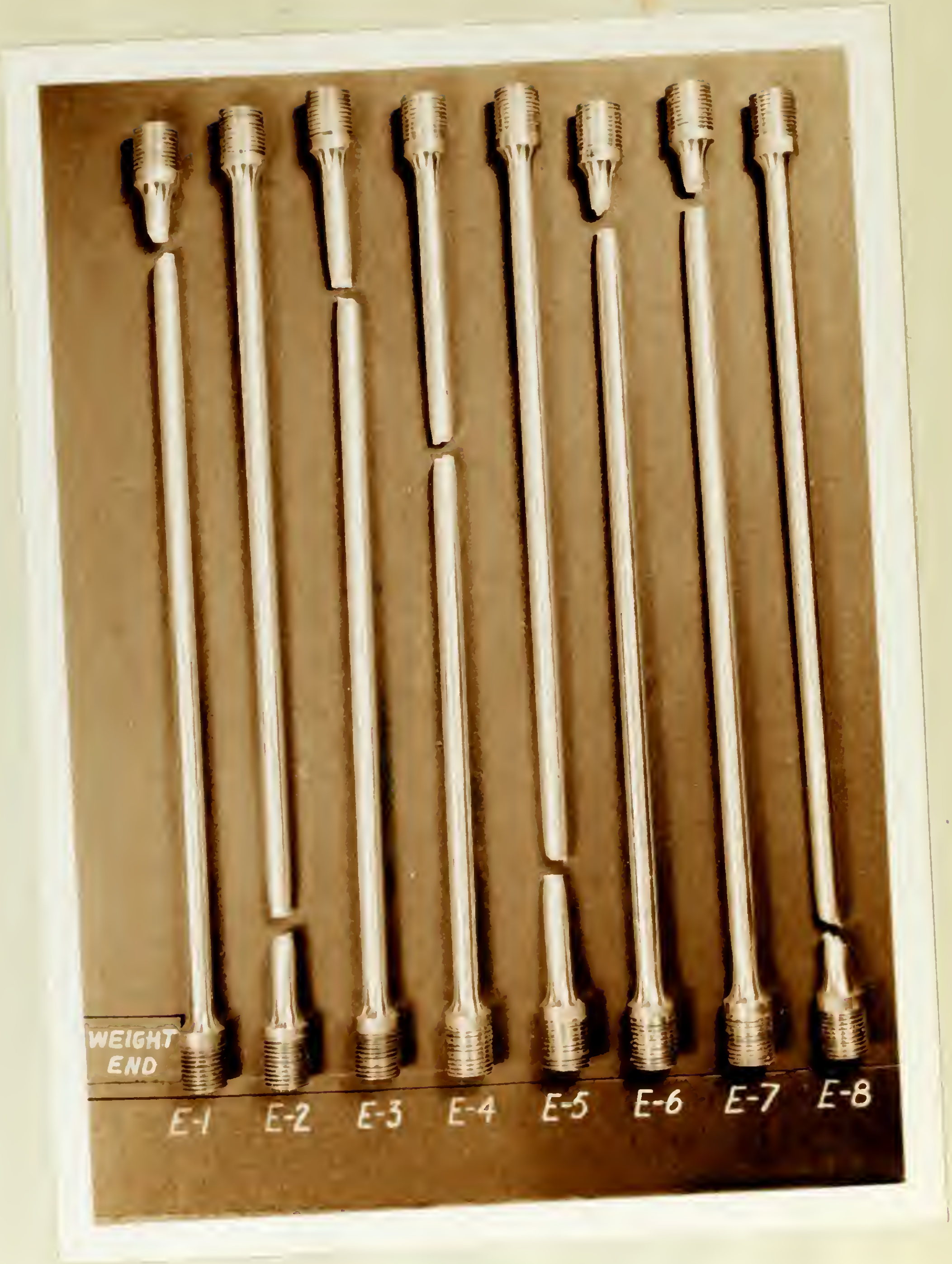


Fig. 11 E Specimens After Fracture

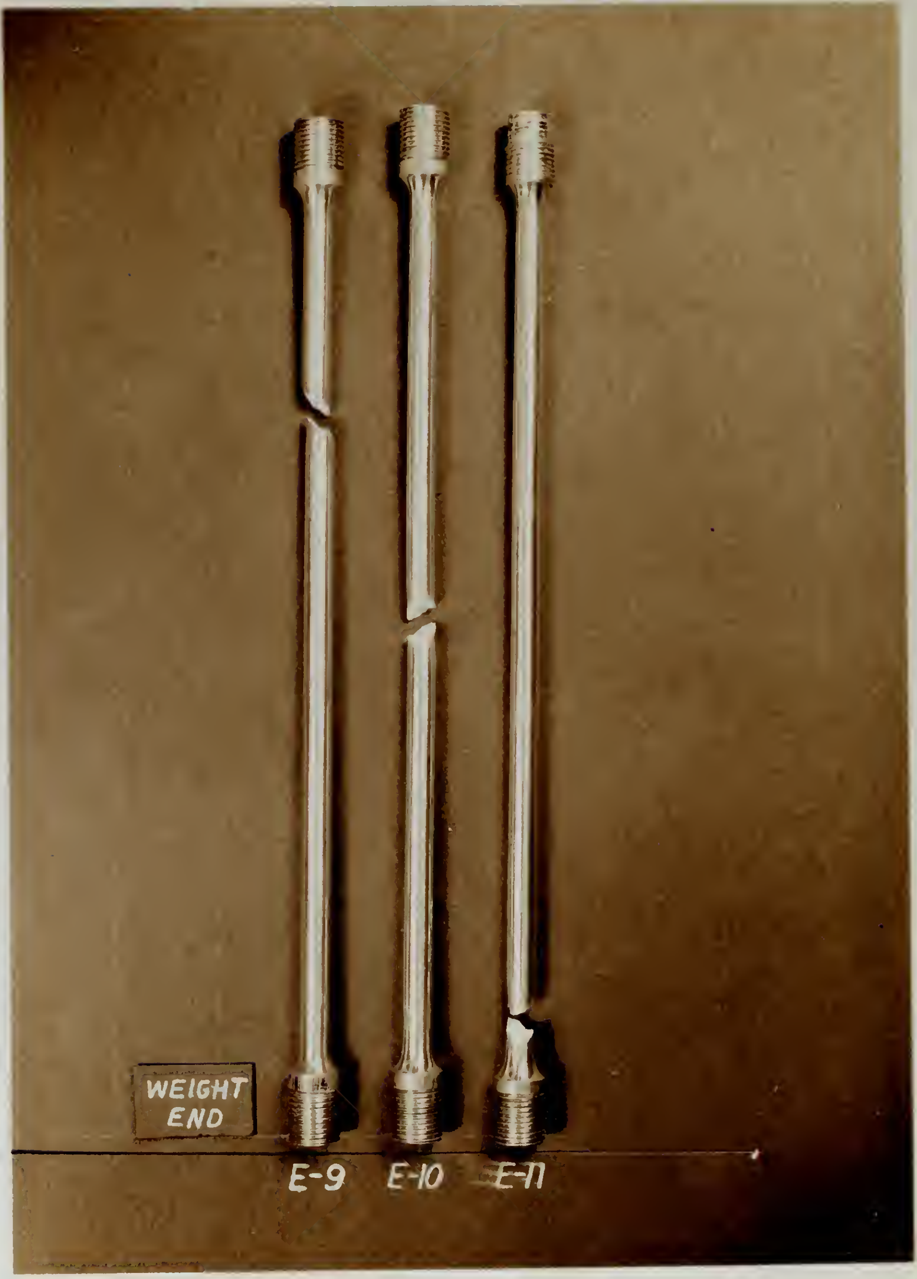


Fig. 12 E Specimens after Fracture

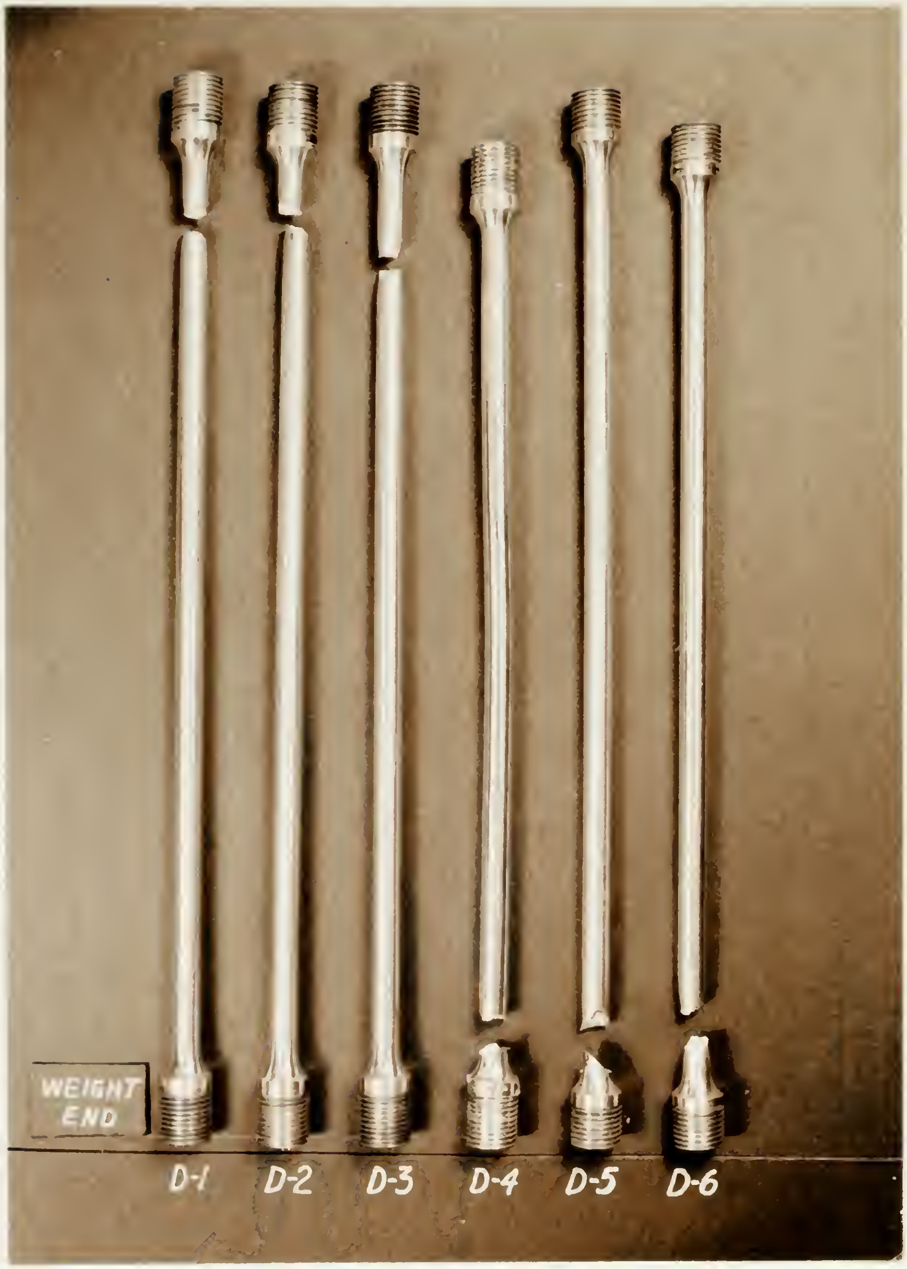


Fig. 13 D Specimens After Fracture

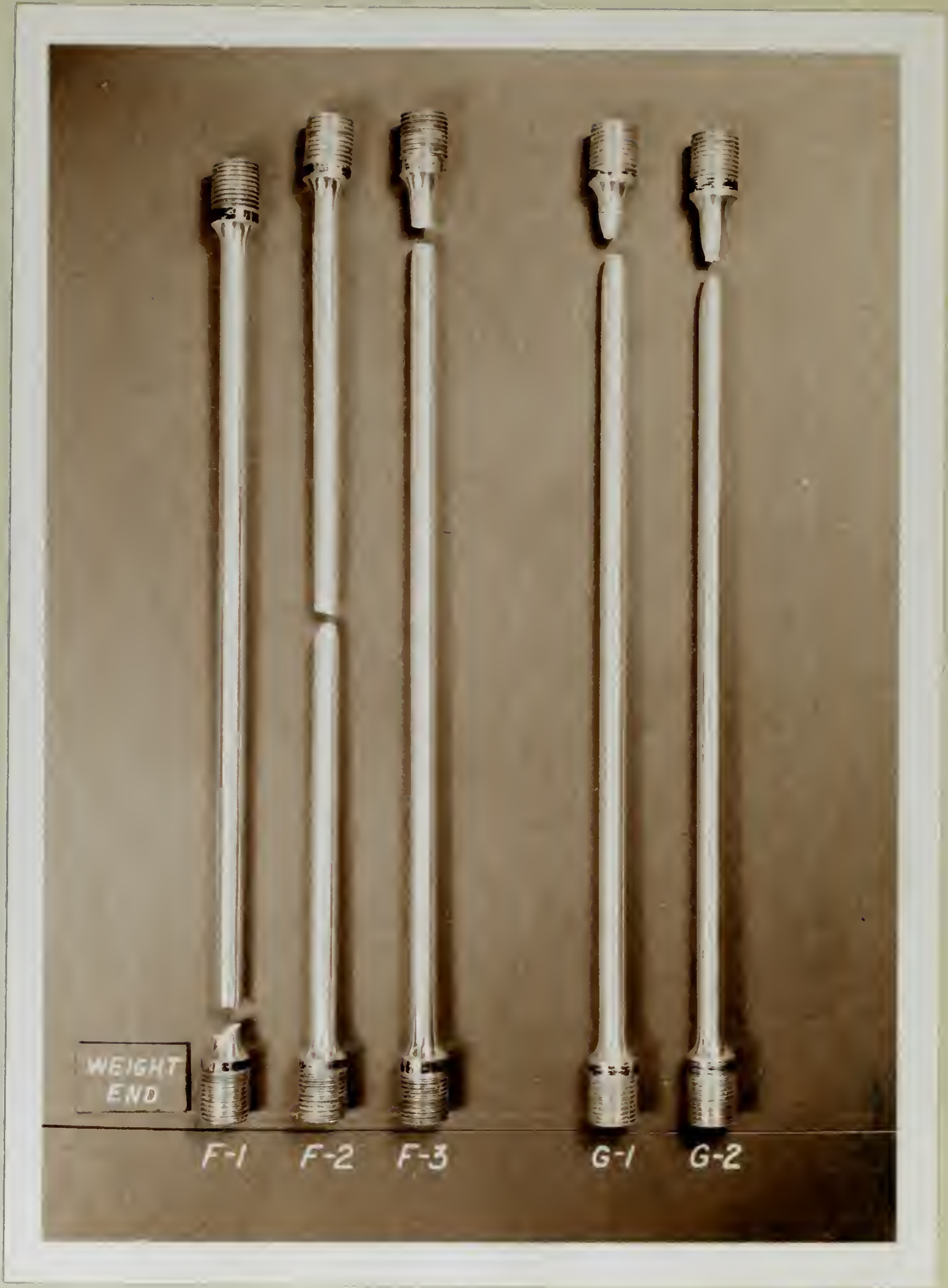


Fig. 14 F and G Specimens After Fracture

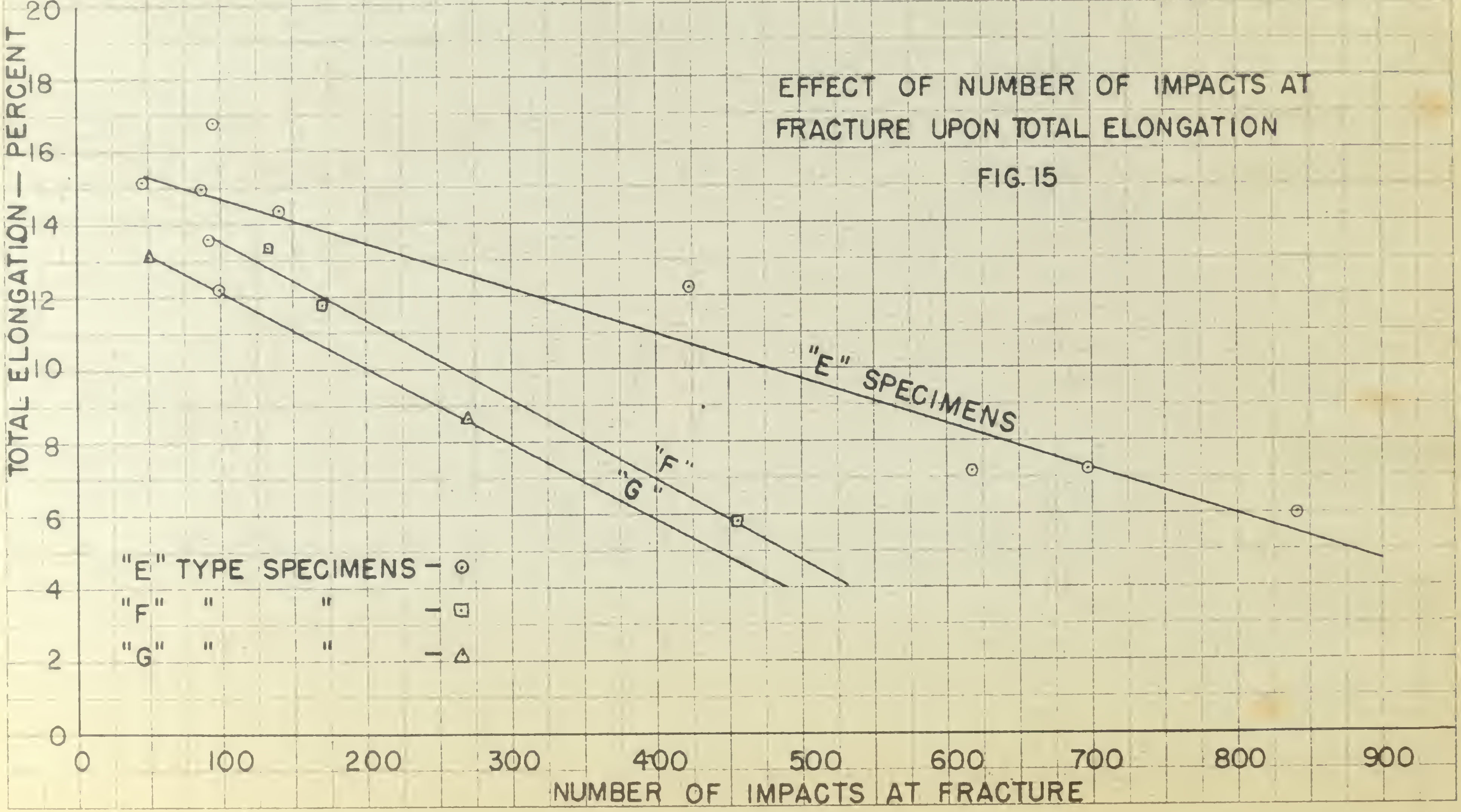
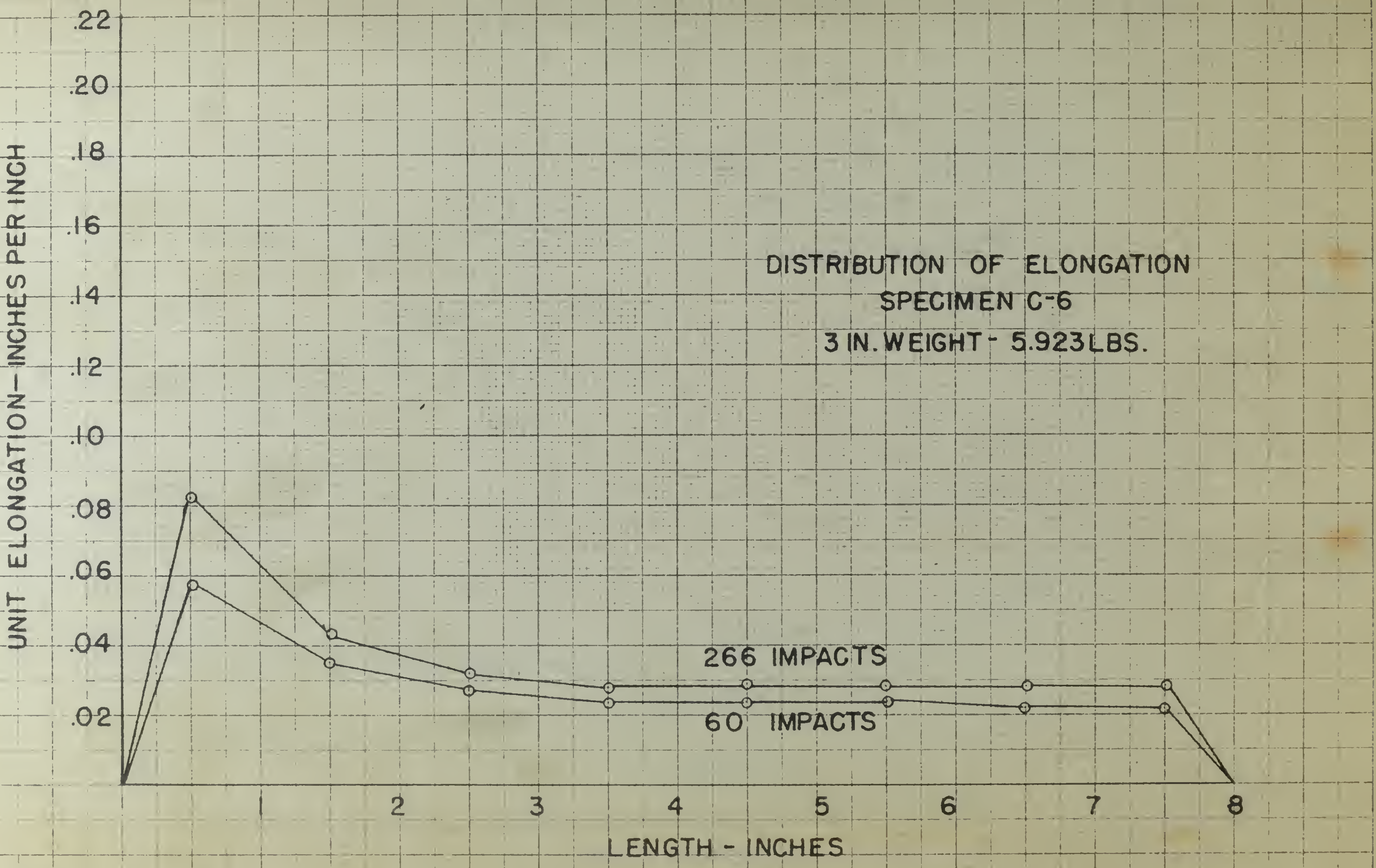
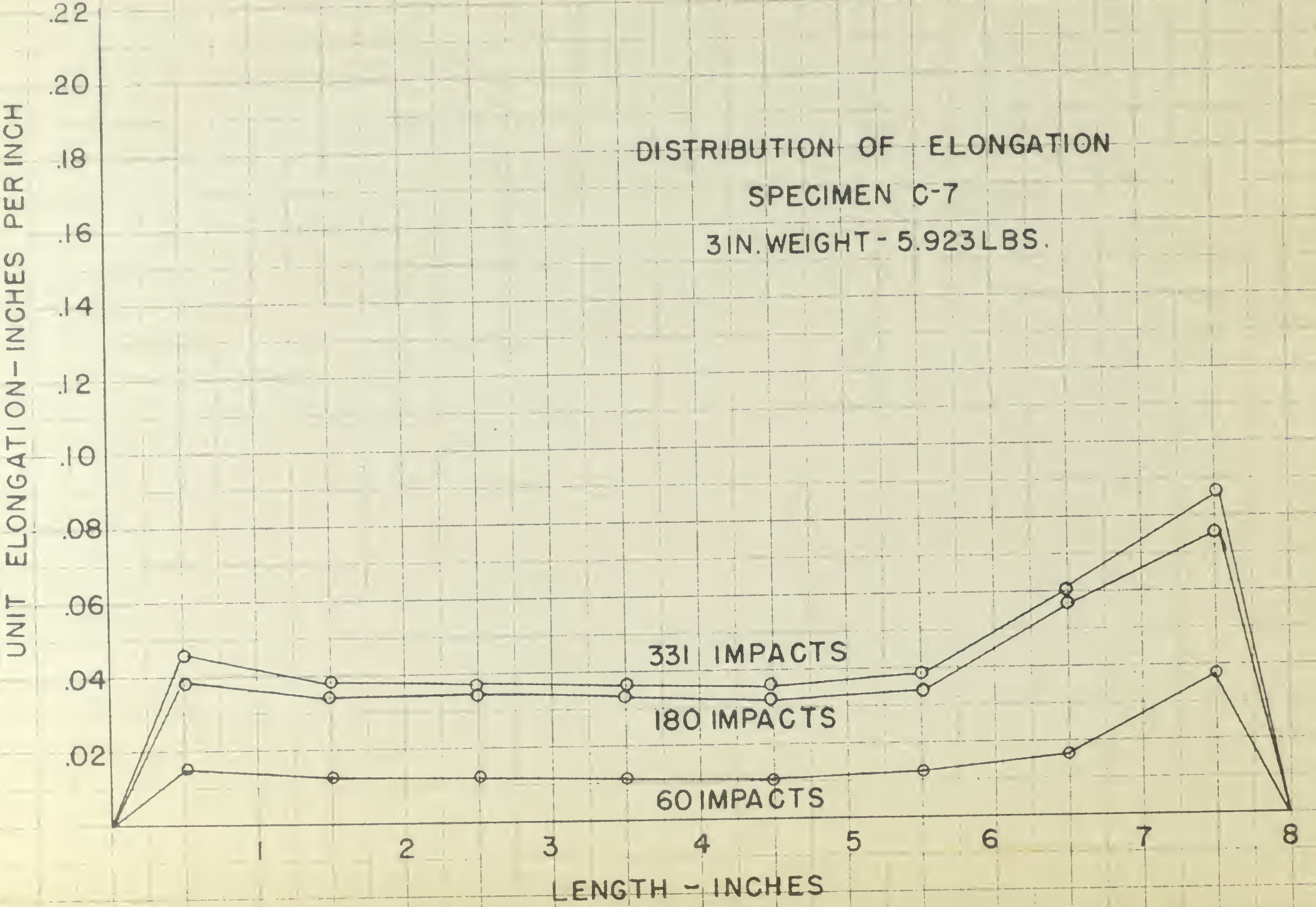

EFFECT OF NUMBER OF IMPACTS AT FRACTURE UPON TOTAL ELONGATION

FIG. 15



DISTRIBUTION OF ELONGATION
SPECIMEN C-6
3 IN. WEIGHT - 5.923 LBS.

FIG. 16



DISTRIBUTION OF ELONGATION
SPECIMEN C-7
3 IN. WEIGHT - 5.923 LBS.

FIG. 17

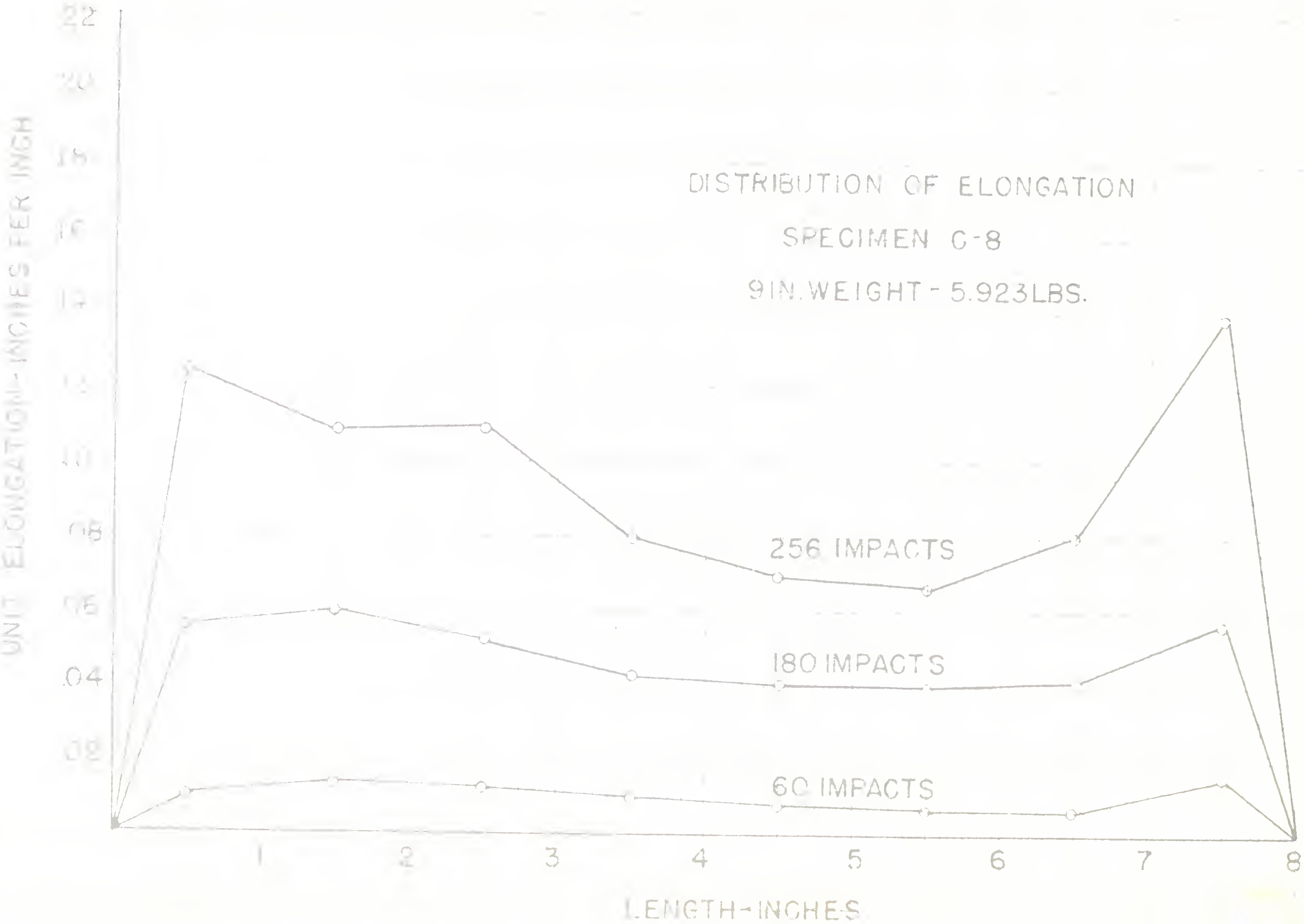
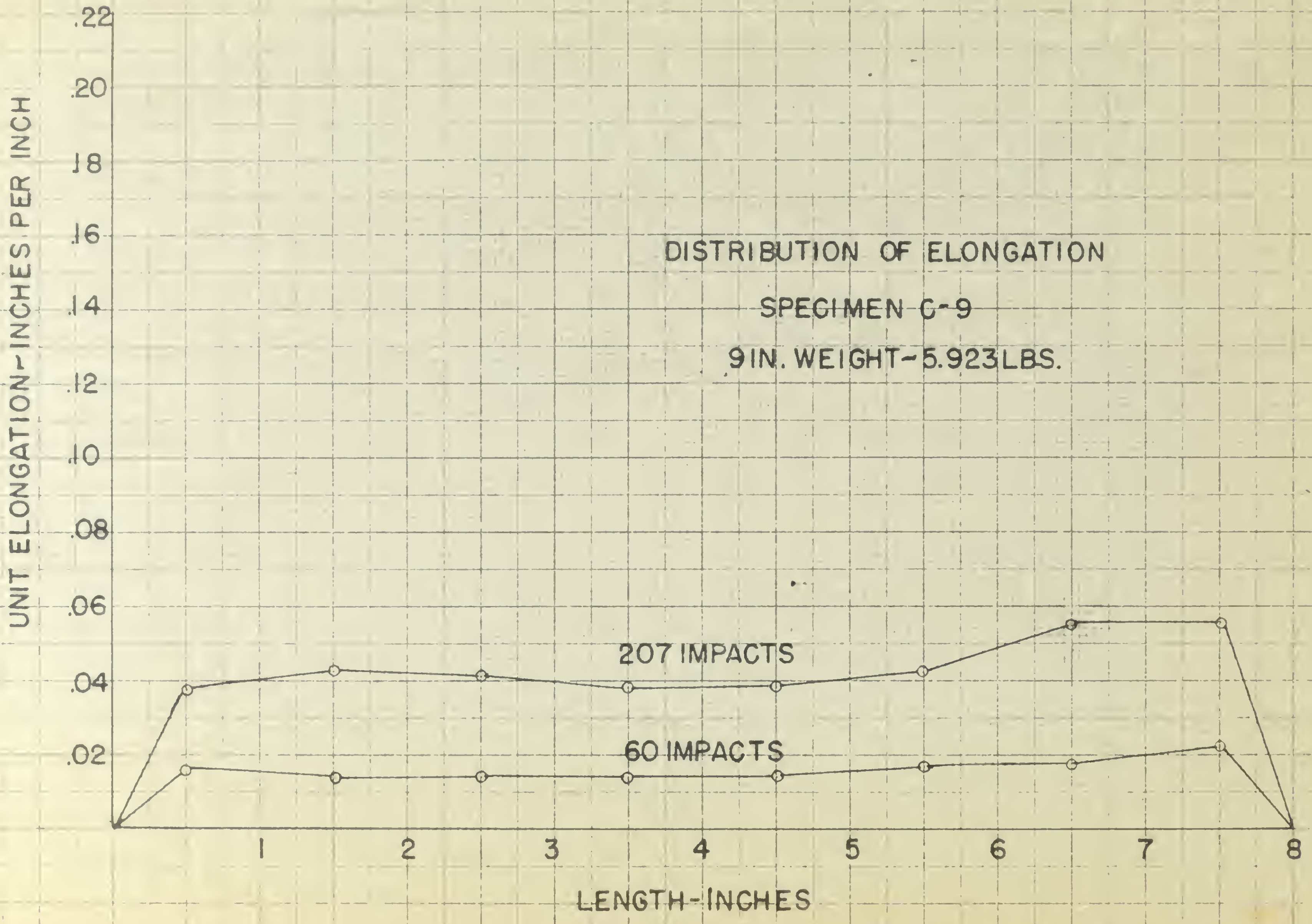

DISTRIBUTION OF ELONGATION
SPECIMEN C-8
9 IN. WEIGHT - 5.923 LBS.
256 IMPACTS
180 IMPACTS
60 IMPACTS
UNIT ELONGATION-INCHES PER INCH
22
20
18
16
14
12
10
08
06
.04
02
1
2
3
4
5
6
7
8
LENGTH-INCHES

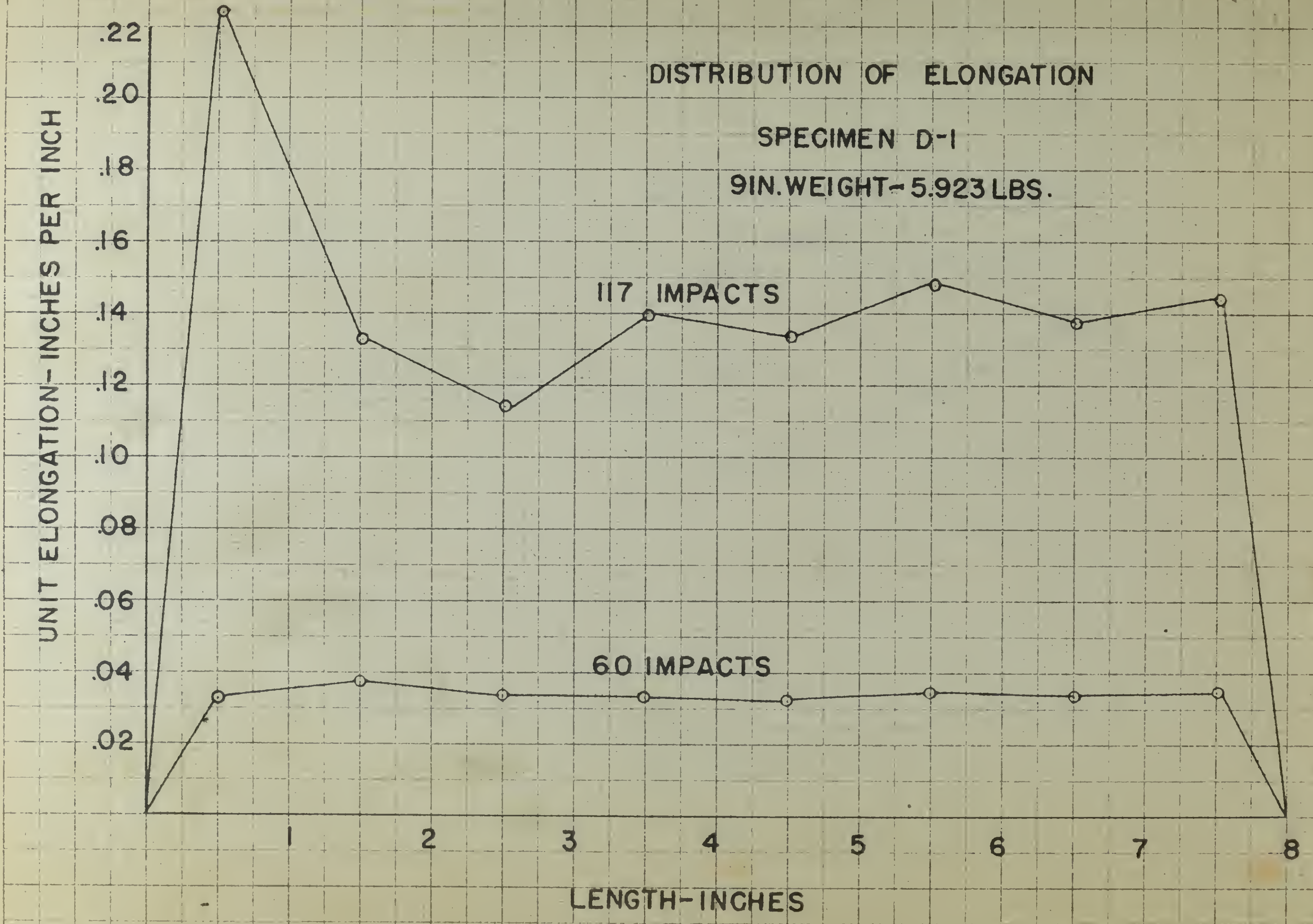
FIG. 18


DISTRIBUTION OF ELONGATION

SPECIMEN C-9

9 IN. WEIGHT-5.923 LBS.

FIG. 19



DISTRIBUTION OF ELONGATION

SPECIMEN D-1

9IN. WEIGHT - 5.923 LBS.

FIG. 20

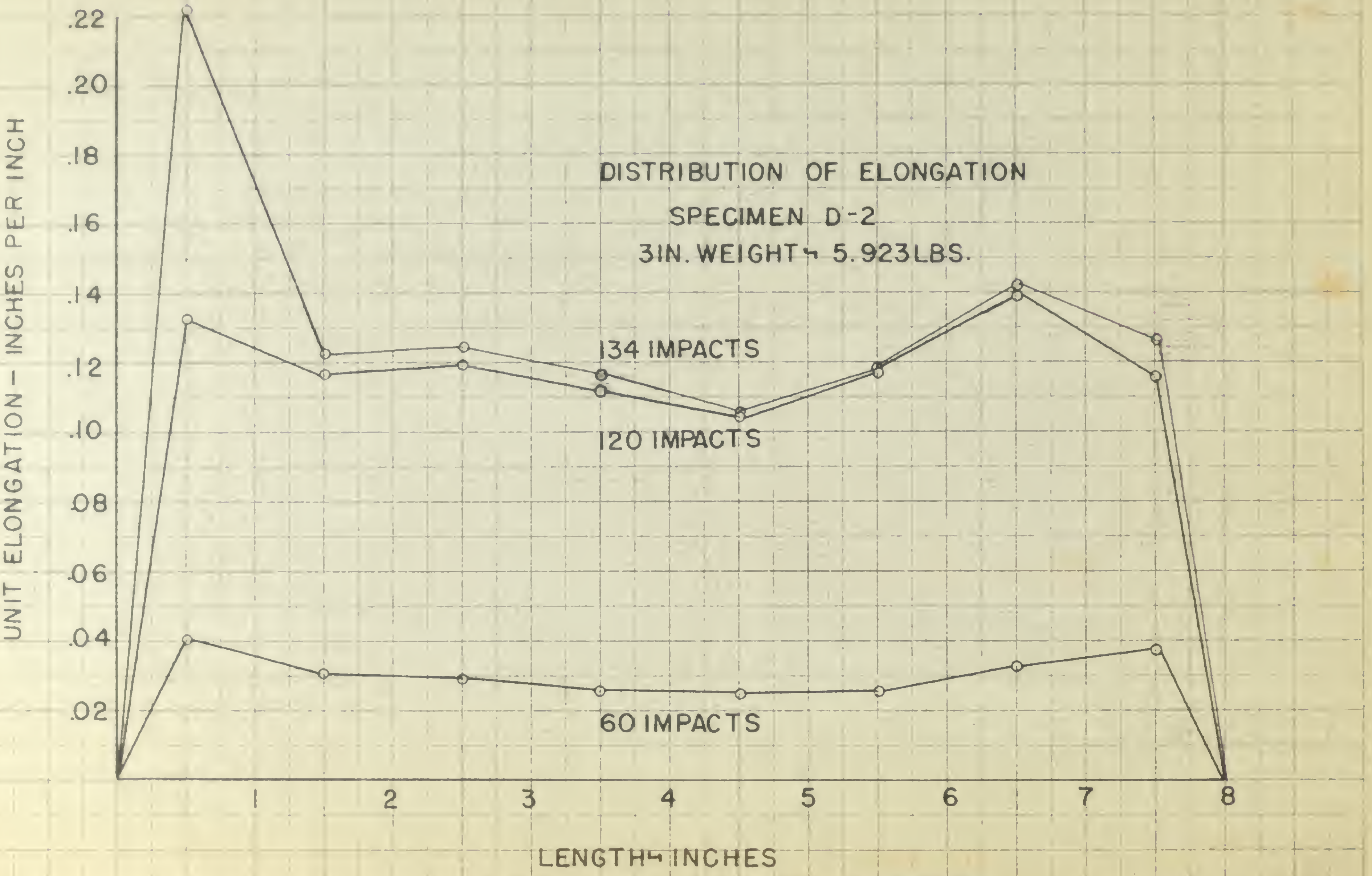

DISTRIBUTION OF ELONGATION
SPECIMEN D-2
3IN. WEIGHT ~ 5.923LBS.
134 IMPACTS
120 IMPACTS
60 IMPACTS
UNIT ELONGATION - INCHES PER INCH
.22
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
1
2
3
4
5
6
7
8
LENGTH ~ INCHES

FIG. 21

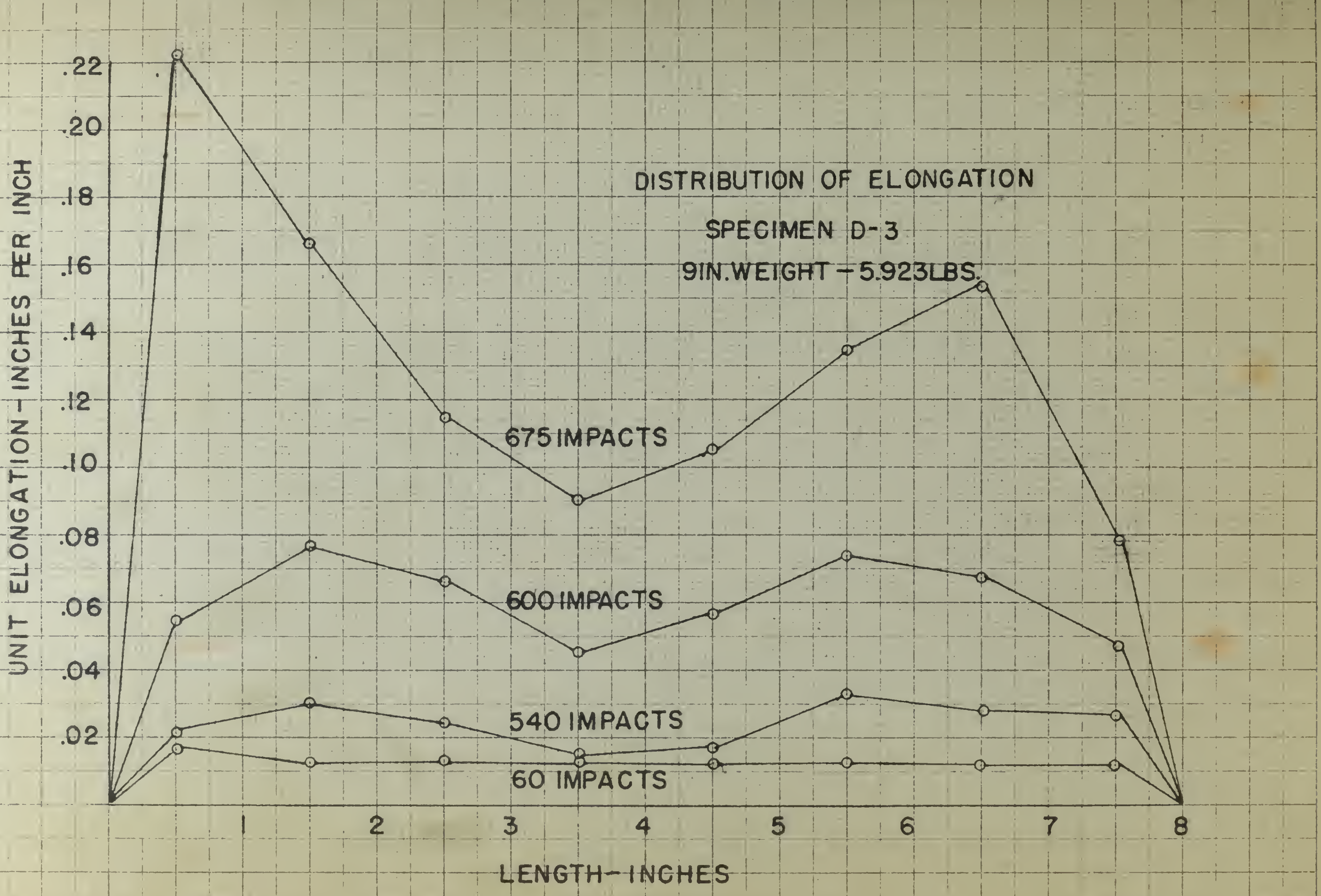

DISTRIBUTION OF ELONGATION
SPECIMEN D-3
9IN. WEIGHT - 5.923LBS.
675 IMPACTS
600 IMPACTS
540 IMPACTS
60 IMPACTS
UNIT ELONGATION - INCHES PER INCH
.22
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
1
2
3
4
5
6
7
8
LENGTH-INCHES

FIG. 22

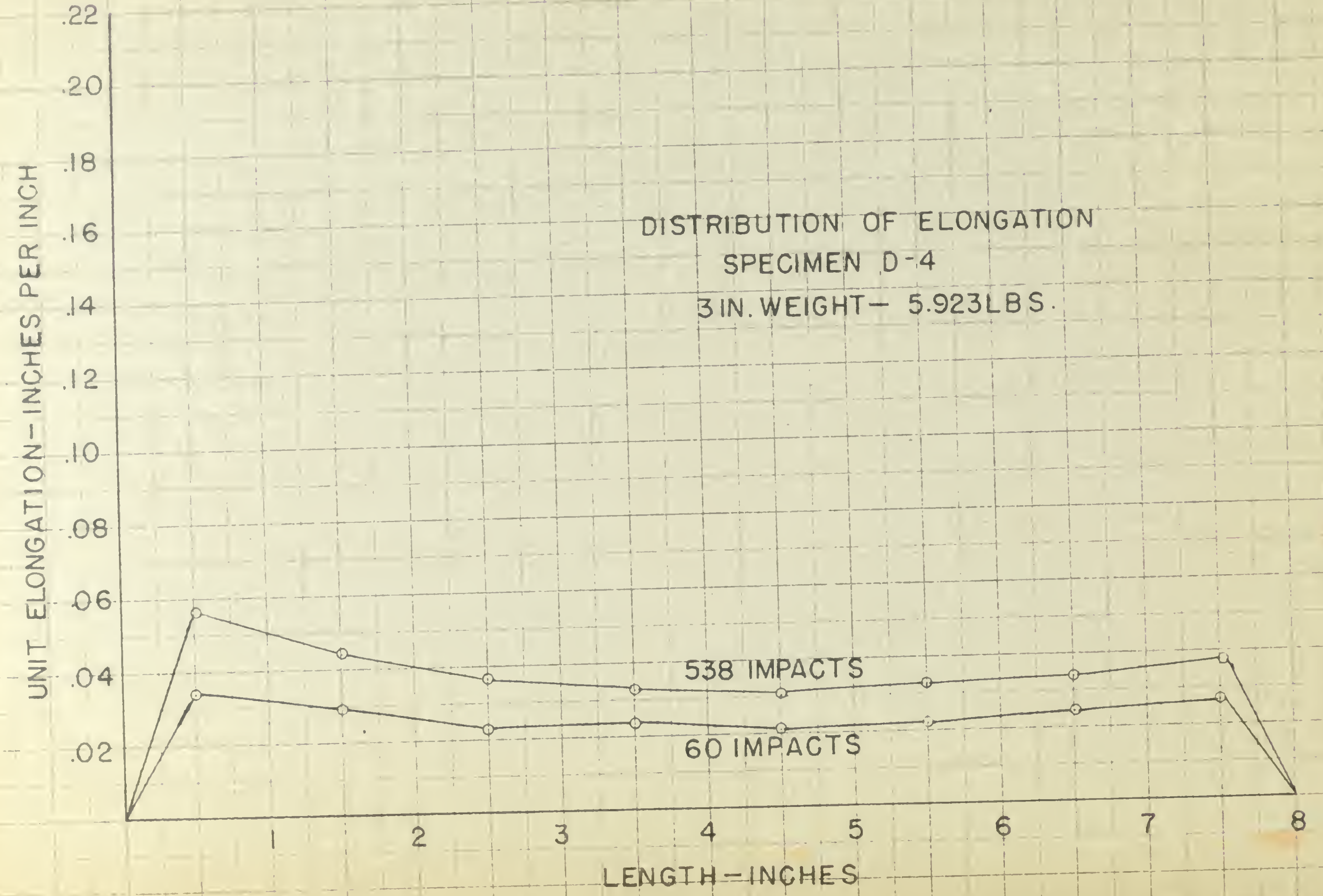

DISTRIBUTION OF ELONGATION
SPECIMEN D-4
3 IN. WEIGHT— 5.923 LBS.
538 IMPACTS
60 IMPACTS
UNIT ELONGATION—INCHES PER INCH
.22
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
1
2
3
4
5
6
7
8
LENGTH—INCHES

FIG. 23

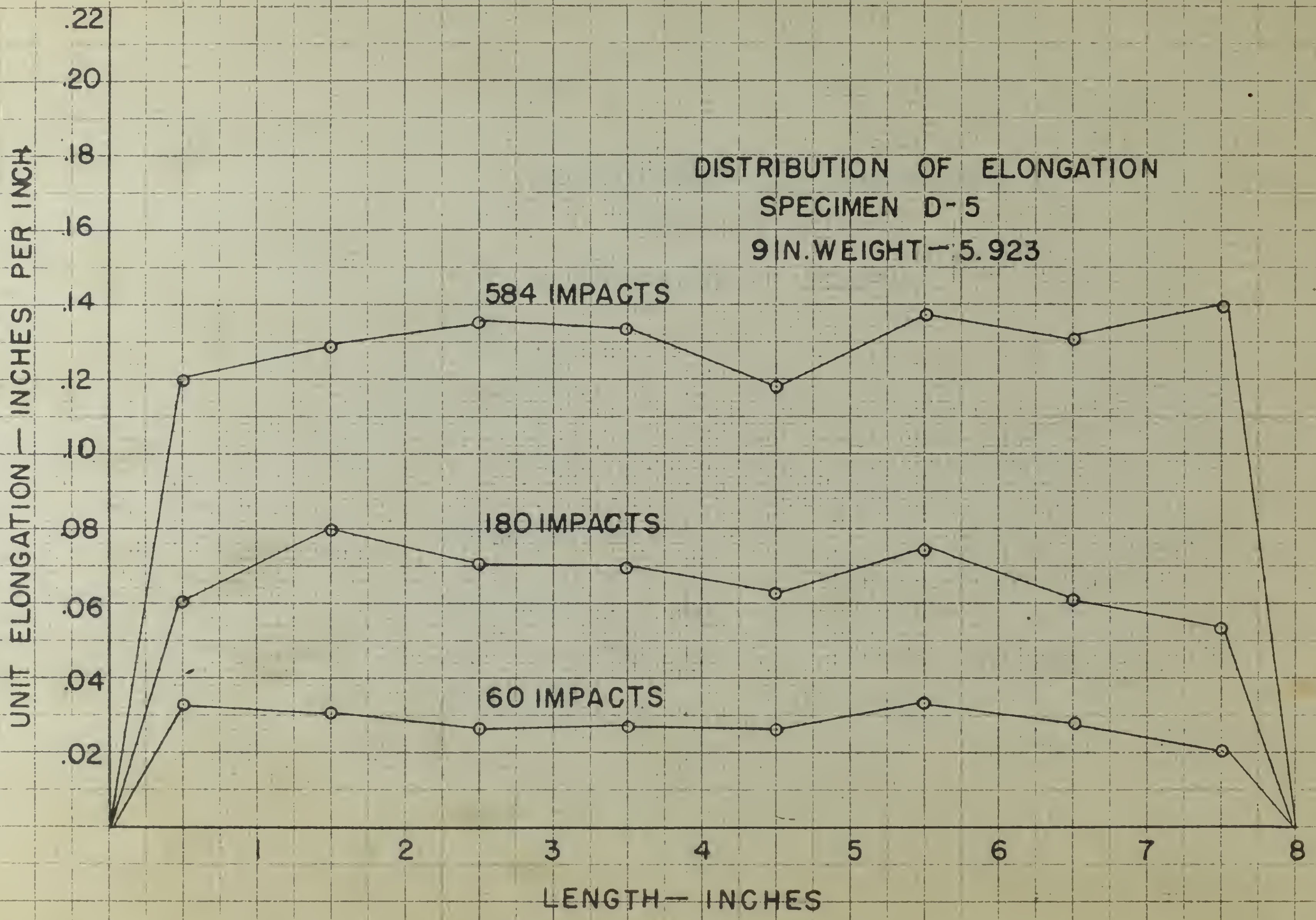

DISTRIBUTION OF ELONGATION
SPECIMEN D-5
9 IN. WEIGHT — 5.923
584 IMPACTS
180 IMPACTS
60 IMPACTS
UNIT ELONGATION — INCHES PER INCH
.22
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
1
2
3
4
5
6
7
8
LENGTH — INCHES

FIG. 24

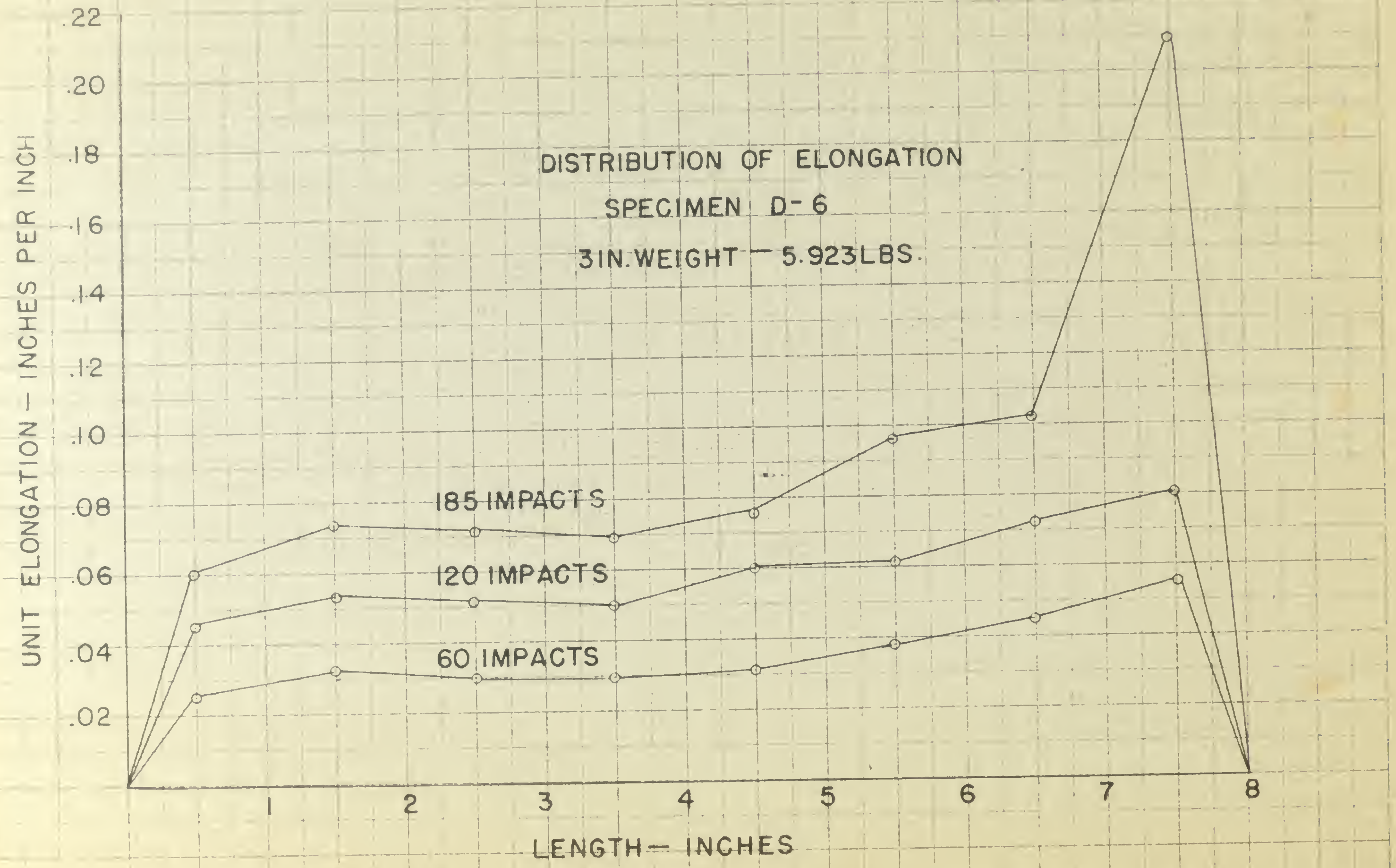

DISTRIBUTION OF ELONGATION
SPECIMEN D-6
3 IN. WEIGHT — 5.923 LBS.
185 IMPACTS
120 IMPACTS
60 IMPACTS
UNIT ELONGATION — INCHES PER INCH
.22
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
1
2
3
4
5
6
7
8
LENGTH — INCHES

FIG. 25

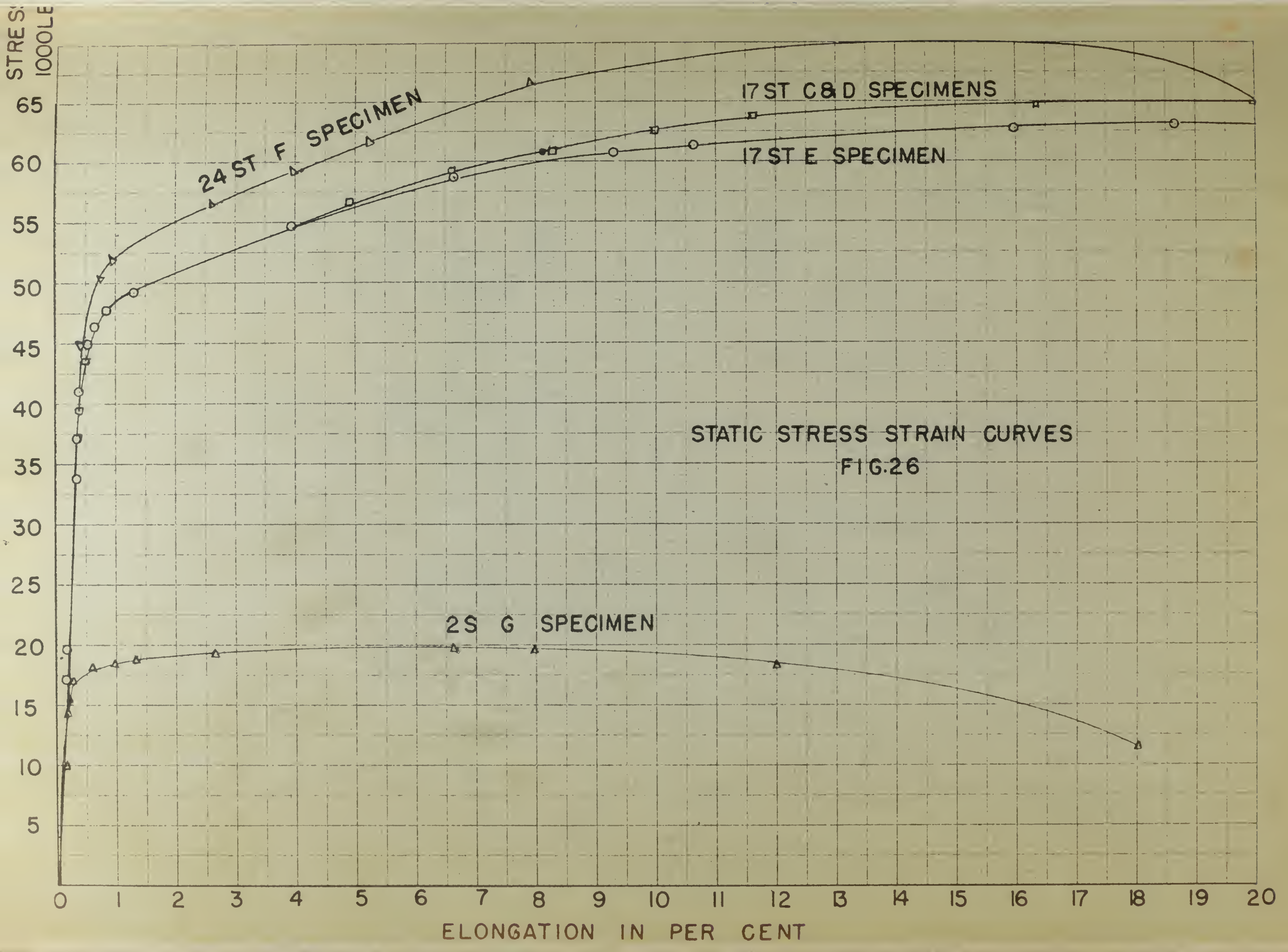
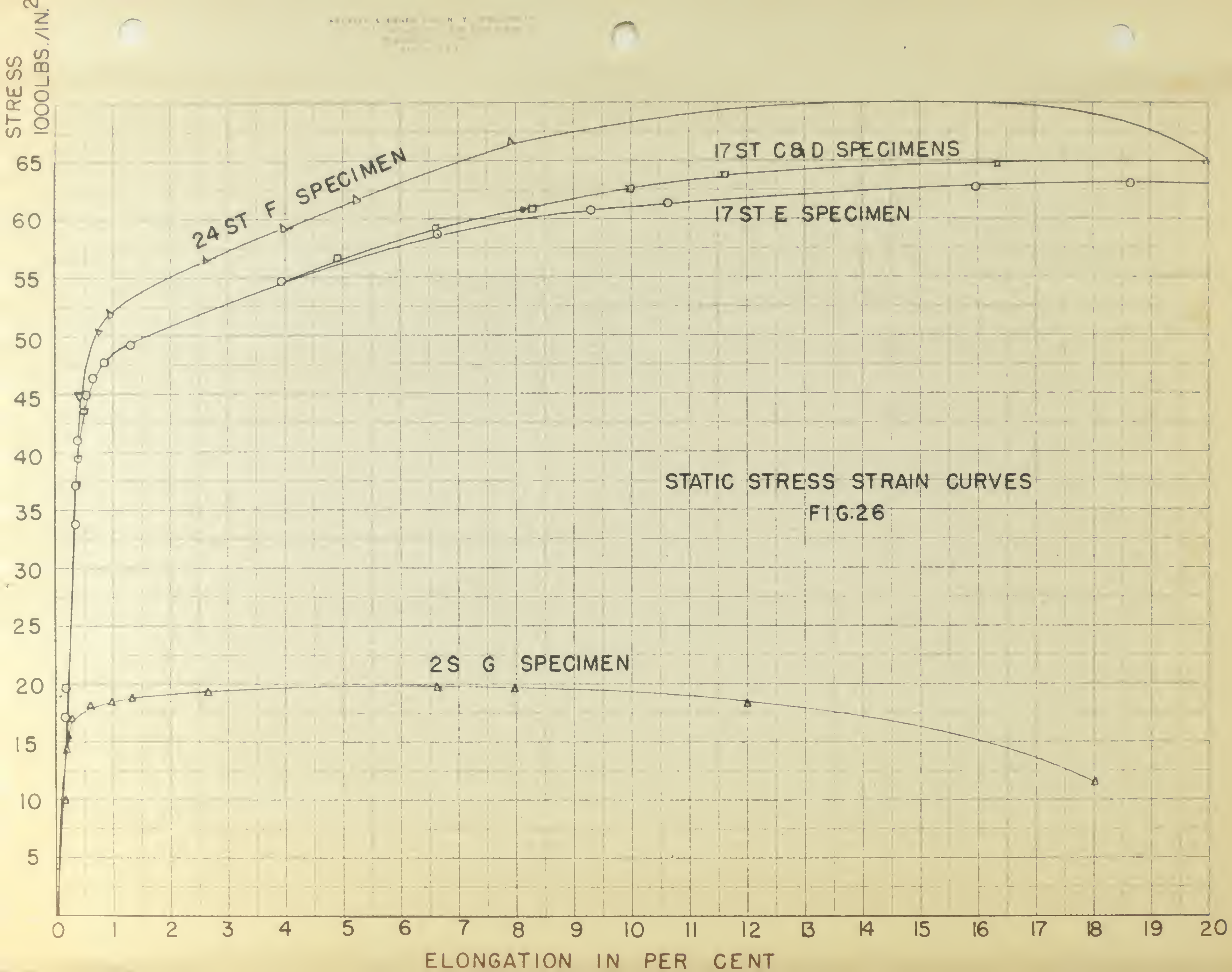
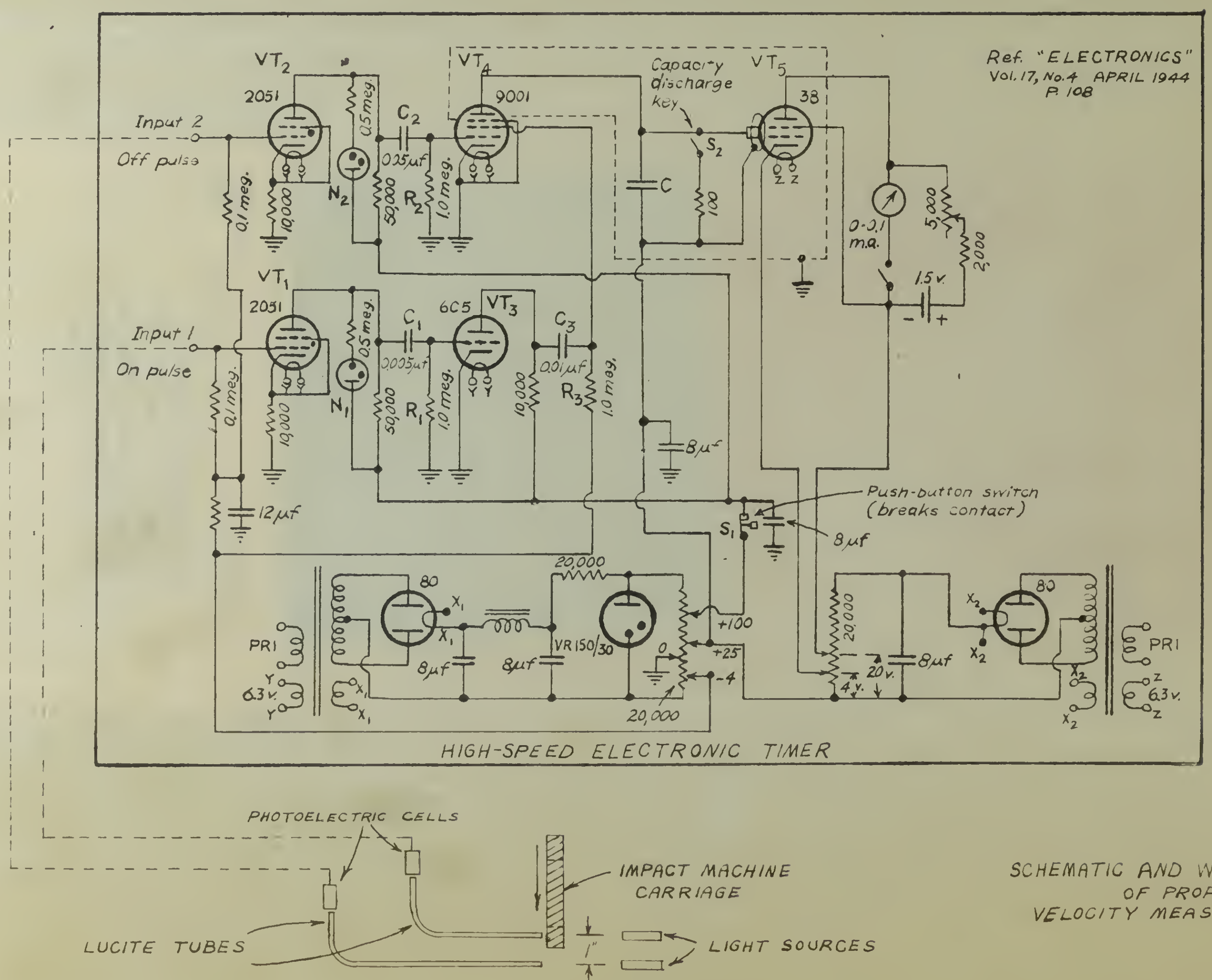

STATIC STRESS STRAIN CURVES

FIG.26

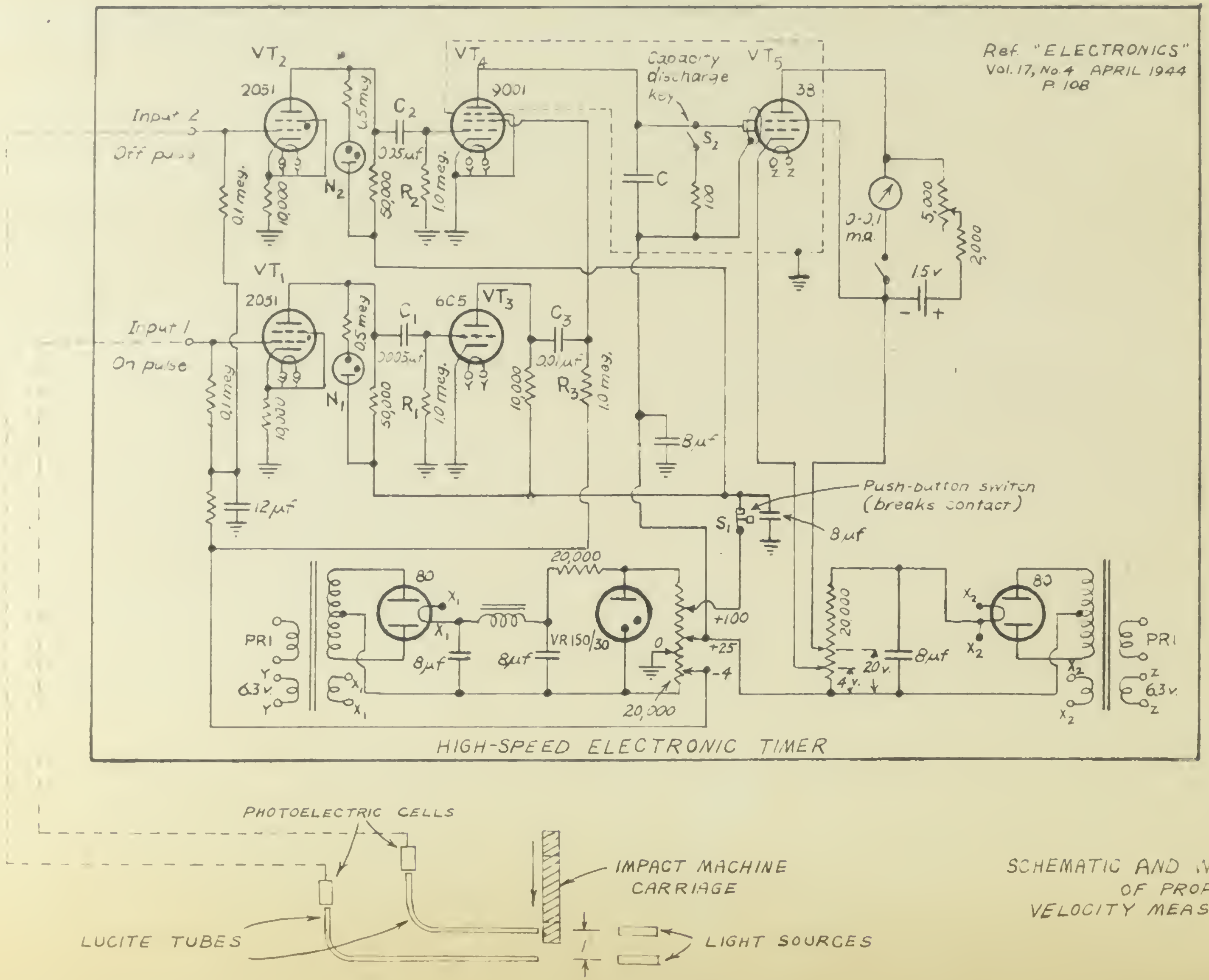


STATIC STRESS STRAIN CURVES
FIG. 26



SCHEMATIC AND WIRING DIAGRAM
OF PROPOSED
VELOCITY MEASURING DEVICE

FIG. 27



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